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Thesis

THE CAUSES AND PREVENTION OF RIVER FLOODS

Submitted by

Andrew Philip Haan

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Contents

Introduction

There are few streams which are not subject in their natural state to great variation in flow. In general, however, rivers at certain seasons have periods of high water, varying in length, during which they may overflow their banks. In sparsely inhabited countries the flooding of land adjoining a river may continue without causing serious difficulties, but when population has considerably increased, then the regulation of such streams that are subject to overflow often becomes a necessity.

The interests of the agriculturist in the region adjacent require that the streams be confined to their proper channels in order to prevent injury to his land and crops.

The manufacturer and property owner in the threatened area also desire that they should not suffer from damage due to floods.

Effects of Floods

1. Direct

a. Loss of life

The Yang-tse-Kiang has been called the most ruinous flood-river on earth.[1] In a period of two hundred years its

1. Oswald, F.L. Floods and their causes. (Lippincott's, 1889, v.44: 242.)

torrents have fourteen times forced the massive dams of the central provinces and each time covered its banks with thousands of human corpses. A terrible flood occurred in 1888, spreading its havoc over an area of three hundred and fifty thousand square miles, including some of the most densely populated districts of Eastern China. The loss of life on that occasion has been computed to have reached seven hundred and fifty thousand,- even after deducting the hundreds of thousands that succumbed to the subsequent famine and the many hundred slain by marauders and hunger crazed cannibals.

The Johnstown flood of 1889 destroyed 2,235 lives.

In April and May, 1912, the Mississippi reached a height never before equaled, and killed 1,000 persons.

The great loss of life was the most serious aspect of the Ohio flood of 1913. It is estimated that 467 lives were lost.

b. Property loss- real and personal

The Johnstown flood of 1889 swept away ten millions of dollars worth of property.

The Pittsburgh flood of March, 1907, injured or destroyed quantities of personal effects. The 1907 flood is estimated to have covered 1,600 acres of land in Pittsburg, overflowing property valued at about \$ 150,000,000. The total flood loss along the Ohio River for the year 1907 was esti-

mated by the Indiana Waterways Commission to exceed $ 100,000,000.[1]

The floods of 1912 were very extensive. Damage to the amount of $ 50,000,000 was caused by the Mississippi in April and May 1912. Governor Cox of Ohio estimated that the damage in Ohio alone by the floods of 1912 was more than $ 300,000,000- nearly as much as the cost of the Panama Canal. The total cost of the floods of 1912 has been estimated as more than that of the Panama Canal.[2]

Hundreds of houses, substantial buildings in the residence districts, many of them with helpless occupants, were washed away in the Dayton, Ohio, flood of 1913. The total estimated flood loss in Dayton as determined by the Dayton Citizens' Relief Committee was $ 73,249,040.

This same flood caused levees and bridges to collapse at Columbus. The property loss at Columbus was placed at from $ 15,000,000 to $ 30,000,000.

At Cincinnati the river-front and low-lying residential sections were flooded. The direct loss was placed at more than $ 2,000,000.

1. Alvord, John W. and Burdick, Charles B. Relief from floods: the fundamentals of flood prevention, flood protection and the means for determining proper remedies. (New York. McGraw-Hill Book Co., 1918. p. 7.)

2. Marshall, Logan. The true story of our national calamity of fire, flood and tornado. 1913. p. 315.)

Over 100 municipalities in Ohio were affected by the flood. There were approximately 2,220 houses destroyed and 40,637 residences flooded.

The property damage at Peru, Indiana, totaled $ 3,000,000.

Many millions of dollars worth of property were destroyed in Pennsylvania.

Table I. Total Estimated Flood Losses of the United States, 1900 to 1908.

1900	$ 45,675,000
1901	45,438,000
1902	55,201,000
1903	97,220,000
1904	78,841,000
1905	98,589,000
1906	73,124,000
1907	118,238,000
1908	237,860,000

(From Relief from floods: the Fundamentals of flood prevention, flood protection and the means for determining proper remedies, p. 4.)

c. Damage to transportation, mail, and telegraph facilities.

The flood of Dayton, Ohio, and the whole of the Miami Valley occurred on Tuesday, March 25,1913. Thousands of persons, who could not get home, were crowded in the upper stories of tall office buildings and residences, two miles each way from the center of the town. Water ran eight feet deep at a point three miles beyond what had heretofore been considered the danger line. It has been estimated that more than 70,000 persons either were unable to reach their homes or, held in their waterlocked houses,were unable to reach land. The flood swept away railroad and wagon bridges over the Miami River.

A tremendous downfall of rain in New York, March 24th and 25th,1913, developed floods which washed away bridges and blocked trains.

The flood of 1913 washed out tracks and caused lines to fall down in Pennsylvania.

The flood in the Ohio Valley stopped trains.

The Lake Shore and Michigan Southern was the only railroad which was working between New York and Chicago on the night of March 26,1913. Over this line were sent the trains of other railroads. The derailment of many trains occurred in flooded territories.

The damage to railroad property in the flooded Middle West, plus the loss entailed by the suspension of traffic, was conservatively estimated as from $ 10,000,000 to $ 15,000,000.

The floods in the Middle West practically put out of business the entire railway system of Ohio and Indiana for five days. Railway officials stated that to repair and replace the railways affected by this disaster would practically wipe out the surplus earnings of many railroads.

The Postmaster-General[1] announced on March 26th that the destruction wrought by the floods in Ohio and Indiana was so serious that it would be ten or twelve days before a regular mail service could be resumed with the remote districts.

It was shown by reports that never before in the history of the service had there been such a serious interruption to the mails on account of floods.

Mr. Marshall[2] says that never before in the history of the United States was there such a general prostration of telegraph and telephone wires as during the great flood.

1. Marshall, Logan. The true story of our national calamity of fire, flood and tornado. p.282.

2. Marshall, Logan. op.cit., p.283.

2· Indirect

a· Increase of disease

The effect of the flood of March, 1907, at Pittsburgh in increasing certain kinds of disease is shown by a comparison of the pneumonia and typhoid records in the flooded wards of Pittsburgh· Dr·Beaty of the Pittsburgh Bureau of Health gives us the number of cases of these two diseases in certain wards on the North side, which are largely tenanted by laborers, and were partly inundated·

In March and April, 1906, when there was no flood, there were fourteen cases of pneumonia and forty-eight of typhoid fever·

In March and April, 1907, when the flood had a height of thirty-six feet, there were forty cases of pneumonia and 118 cases of typhoid fever, more than twice the number of preceding years·[1]

During the flood the water and dwellings in these districts became badly contaminated by human waste, since the flooding of toilets and sewers prevented their use· At the same time many families usually dependent upon street hydrants for domestic water had to make use of this extremely impure river water· This affected large numbers of people, many of them recently arrived foreigners unacquainted with methods of securing ready relief·

1· Ashe,W·W· Effect of forests on economic conditions in the Pittsburgh district· p·828· Charities v·21·

A strong sanitary organization is needed after floods to remove the sources of infection. If the state is unable to assume control, the United States government may be appealed to.

The Mississippi Valley flood of 1927 was battled by health and sanitation forces on a scale unparalleled in the peace-time history of this country.

Ninety-two nurses, fifty-eight doctors and thirty sanitary engineers were on duty on May 27th in the seven states affected. Outbreaks of disease were being checked satisfactorily, with actual less disease, in Dr. Redden's[1] opinion, than under normal conditions. Dr. Redden said that an exhausive survey of the terrain was made which showed that Arkansas had 15,000 head of dead livestock and Mississippi 25,000. To neutralize the menace plans were made to send 50,000 pounds of chlorinated lime to be used in the two states and one carload of dehydrated lime per county in addition.

Pestilence outbreaks in the Mississippi Valley were prevented by the nation's health armies. Dr. Hiscock,[2] of the Yale School of Medicine, said that the incidence of disease was less than that normally to be expected.

1. Science. New Series, May 27, 1927, v. 65: supplement 10.
2. Science. New Series, August 5, 1927, v. 66: supplement 10.

A concerted drive on the three most feared diseases, malaria, typhoid fever and summer diarrhea, was made by the Red Cross working in cooperation with federal and state health authorities. Camps, stores, doctors' offices and any convenient place served as immunization clinics where some 560,000 people were completely immunized against typhoid and 161,000 were vaccinated for smallpox.

Two tons of quinine and 200,000 gallons of spray oil for mosquito control were supplied for the war on malaria, and a program was in progress for the complete screening of 15,000 malaria patients. The spray oil was spread over stagnant waters to prevent the maturing of the mosquito larvae. Water supplies were safeguarded and purified as far as possible, but when such precautions were out of the question educational campaigns were instigated to boil drinking water and milk to protect hundreds of homeless babies from summer diarrhea.

Complete care throughout the refugee period was given to about 600,000 people.

There is little danger of contracting disease from previous healthy men and animals. The remains of persons ill of, or killed by disease may be a source of infection.

b. Loss of wages

Floods may have an important bearing upon the wages which employees receive. The earnings and even the

lives of thousands, especially of those living in the low districts of the larger cities in the Pittsburgh section, are threatened by the winter and spring floods. These floods frequently result in losses to wage earners aggregating several million dollars a year. In the flood of March, 1907, it is estimated that more than 2,000 families in the river districts of Pittsburgh, and an equal number in the low lying sections of nearby cities, were forced from their homes or their stores by high water.

The flood of March, 1907, at Pittsburgh caused suffering by the loss in wages through the closing of large establishments whose plants were flooded. It was estimated at the time by one of the local newspapers that more than 100,000 people in the Pittsburgh District were idle for an average period of a week. The losses to laborers by curtailment of wages on account of floods amount annually to more than $ 100,000. This loss takes place in the winter when the wage earner can least afford it.[1]

c. Fires

Fires may be started in times of flood. The horror of the flooded district of Dayton in March, 1913, was heightened by more than a dozen fires which could be seen in the flooded district, but out of reach of fighters. Fires broke out at Columbus during the flood of March, 1913.

1. Ashe, W.W. Charities, Feb. 6, 1901, v. 21: p. 828, 831.

Some time ago a river near Augusta, Georgia, overflowed its banks and inundated the basement of a store that contained unslaked lime. The water acting upon the lime caused it to slack and give off enormous quantities of heat. That building and several others were burned down by the fire that followed.[1]

Barns were inundated with water in the flood that swept through Vermont not so long ago. Several strange fires that followed in the flood's wake were traced to the wetting of the hay. Two days after the flood had receded one farmer's hay-filled barn near Middlesex, Vermont, caught fire. Hot drafts had been produced by the heat generated in the wet bottom layers of the hay pile until the close-packed mass caught fire.[2]

Causes of Floods

There are various causes of floods with several contributing factors.

1. Sudden and violent rain-showers falling upon an unusually heavy snowfall.

Sudden and violent rain-showers falling upon an unusually heavy snowfall may cause a flood, even in densely-wooded highland regions. The valley of the Tennessee

1. The Literary Digest, Jan. 5, 1929, p. 31.

2. The Literary Digest, Jan. 5, 1929, p. 32.

River and other North American streams are visited at long intervals by such floods. The highest floods of the Allegheny and Monongahela Rivers occur when a deep snow on a frozen soil is suddenly melted by heavy warm rain.

2. Formation of an ice-gorge

The formation of an ice-gorge in the rivers of the higher latitudes may cause them to overflow their banks. Such floods are chiefly liable to take place on streams running from south to north, owing to a possibly considerable difference in the temperature of their upper and lower valleys. The warm rains of the (southern) headwater regions may set afloat masses of drift-ice which may encounter the rigid barrier of a frozen delta and in a few hours cause the river to rise with a rapidity rivalling the consequences of a cloud-burst. The St. Lawrence on this side of the Atlantic, and the Oder and Vistula in the Old World, have thus more than once turned their lower valleys into inland lakes.

A glacial dam formed across a river may produce a similar result as an ice barrier formed by the river itself but on a larger scale. Twenty million tons of water were rushing on August 13,1928 upon the valley of the Indus through mountain gorges tributary to the Shyok River in Kashmir.(The Boston Globe. Boston,Mass. Aug.13,1928) The breaking of a glacial ice dam 1000 feet wide and 1200 feet thick which had formed 140 miles north of Len set free the water.

The little Khumban Glacier in 1926 thrust its nose across the Shyok Valley at this point. The waters had been piling up for two years, forming a lake nine miles long, 17,000 feet above the Indus Valley. The British officials had long foreseen the event and had posted signal men for miles at intervals below the lake, ready to give flood warning by bonfires and cannon. Unfortunately we do not know what damage this flood caused as we have not found any additional information dealing with this flood.

3. Phenomenal rainfalls- "cloud-bursts"

Well-wooded countries may even be visited now and then by phenomenal rainfalls with short, but destructive, inundations. The waters of the Brahmapootra have occasionally been raised by the torrents of the rainy season from an average of thirty to eighty, or even eighty-five, feet; and it is on record that on the 9th of October, 1827, there fell at Joyeuse, in the French Cevénnes, between 3:00 A.M. and 11:00 P.M., not less than thirty-one inches of rain.

The occurrence of floods is particularly favored in the Wasatch Mountains. Storms of cloudburst violence are not infrequent during the summer and spring. This great amount of water is unable to be absorbed immediately by the soil, and as a result there is a tendency for it to flow off from the watershed in the form of a flood.[1]

1. Reynolds, Robert V.R. (U.S. Dept. of Agriculture. Forest Service. Bull. 91, p.13.)

A disastrous flood may be brought about by two cloud-bursts, or sudden and heavy rains, occurring within a short interval of each other, when the same rainfall, spread over a month, would have been comparatively innoxious.

4. Landslides

The channels of rock-bound highland streams have occasionally been obstructed by landslides, thus forming mountain-lakes which subsequently burst their barriers with most destructive results. In 1595 a disaster was caused by the eruption of a lake formed by the fall of a rock-avalanche into the valley of the Drance (southern Switzerland); and only a timely alarm prevented the repetition of that calamity at almost exactly the same spot in 1818. A dam three thousand feet long, six hundred thick, and four hundred high was formed by a glacier, followed by a mountain-load of rock-débris, which descended into the valley of the little stream. The rains of the upper valley in a few days swelled the obstructed river into a lake estimated to have contained almost a billion cubic feet of water. The dam burst two weeks later; but the inhabitants of the lower valley had fled to the hills, together with their cattle and every portable piece of property, and the loss was chiefly confined to the demolition of a few mountain-hamlets and the drowning of a herd of cows who,

with ill-timed obstinacy, had returned to their valley-pastures just a few moments before the explosion of the deluge.[1]

5. Blocking of streams by volcanic agencies

Volcanic agencies have now and then caused similar disasters. The valley of Sambuco, in the Mexican State of Michoacan, in September, 1759, gave birth to a new mountain, which in less than forty-eight hours rose to a height of thirteen hundred and fifty feet and completely obliterated the glens of half a dozen little mountain streams. One of these streams reappeared two months later in an eruption of steaming mud, water, and sand, that spread far and wide over an adjoining plain, till the subsidence of the upheaval gave it a chance to force its way through the accumulated hillocks of volcanic cinders. The same earthquake which, in 1837, revived the activity of the volcano of Papandayang on the island of Java caused a landslide that obstructed the valley of the river Kediri,- so effectually, indeed, that the natives celebrated the funeral rites of the entombed stream. The stream began to achieve its own deliverance by filling the crevices of the obstructing rocks with superheated steam, and when the barrier at last gave way the thunder of the descending waters is said to have been heard in the village of Nara Buddor, some forty English miles from the battle-

1. Oswald, F.L. (Lippincott's, 1889, v.44: 238-239.)

field of the contending elements.[1]

6. Collapse of dams

When we consider the number and magnitude of such constructions as dams, it speaks well for the engineering profession that calamities caused by their collapse are so infrequent. The dam itself at Black River Falls, in October, 1911, stood the required strain, but the end does not seem to have been properly protected, and the flood made a channel through the hill there. In the same month the dam at Austin was destroyed. The rock foundation upon which the dam rested was evidently unstable. The water undermined the dam which was anchored eight feet deep, the foundation slid, the dam broke into seven sections and parts of it were overturned.[2]

Alvord and Burdick say that the partial protection given by the low levees at Dayton and at Columbus, Ohio, was responsible for the disasters in these cities in 1913. They say, "Without the low levees which were thought to furnish protection, the damage would have been confined to a wetting. The flood would have risen comparatively slowly and the people would have had time to escape or could have remained in their houses with safety. At

1. Oswald, F.L. (Lippincott's, 1889, v.44: 239.)

2. Causes of collapse. (Current Literature, Nov., 1911, ~~v.~~ v.51: 476.)

both places it was the sudden and unexpected breaking of inadequate levees that caused the great loss of life and the heavy property damage.[1]

Marshall speaks of the breaking of the levees at Dayton, but places the severity of the flood as due to the collapse of the Loramie reservoir. He says, " But the severity of the flood that hit Dayton was due to the collapse of the Loramie reservoir in Shelby County----,hurling millions of gallons of water into the swollen Miami.Rushing down the Miami Valley the water carried everything before it at Piqua, Troy, Sidney, Dayton, Carrollton, Miamisbury and Hamilton."[2]

The Johnstown flood was very destructive. Eight villages were lying in a narrow valley aggregating 50,000 to 80,000 inhabitants, the largest of the eight being situated at the lower end, with about 25,000 inhabitants.

A huge body of water hung far up in the mountain 300 feet above the chief village of the valley. Formerly this had been a small lake with natural outlets, which prevented it from being a menace to the valley below, but an immense dam had been built which held back the water till the lake was more than quadrupled in size.

These were the conditions on May 31,1889. Heavy rains had fallen for several days. The water-shed of the Alleghany Mountains poured its streams into the artificially enlarged lake which acted as a receiving reservoir. The

1. Alvord,John W.and Burdick,Charles B. Relief from floods. p.53.

2. Marshall,Logan. The true story of our national calamity of fire, flood and tornado. p.24-25.

rains had swollen every little stream that ran into it into a torrent. The lake in ordinary times had an area of three and a half miles in length, with an average width of over a mile, and a depth in some portions of 100 feet, but the water entering it had swollen the lake into a volume of water of enormous proportions. A dam nearly 1,000 feet wide, 110 feet high, ninety feet thick at the base and twenty at the top was between it and the valley below. The dam gave way and the water rushed into the valley in a solid wave with a perpendicular front of forty feet.

The seven smaller villages were swept away like straw and hurled, together with uncounted thousands of their inhabitants, upon the larger village, and then, with the accumulated ruin of the whole eight, dashed upon the stone bridge at the bottom of the valley. The shock was withstood by the bridge, and a new dam, as fatefull with horror as the first had been, was formed. This dam held back the water so that the whole valley was a lake from twenty to forty feet in depth, with the remains of its villages beneath its surface. A vast area was covered by the wreckage of the ruined villages, piled from forty to sixty feet high, against the bridge. Countless bodies of the living and the dead were crushed within the wreakage and struggled for life upon it. Fire started in the accumulated ruins and burned the mass to the water's edge.[1]

1. Marshall, Logan. The true story of our national calamity of fire, flood and tornado. p.294-295.

7. Continuation of heavy rain after the ground has everywhere been saturated.

The continuation of heavy rain after the ground has everywhere been saturated may result in a flood. A forested area is not able to prevent floods in the face of heavy, long continued rains.

8. Destruction of forests

The relation of forests and floods has been a subject for discussion for some time. In the following account we will first present the evidence favoring the view that the destruction of forests causes floods. Next, we will present the evidence which is favorable to those who hold that the destruction of forests has no appreciable effect upon floods. Finally, we will try to explain the true relation existing between forests and floods.

a. Belief in destruction of forests as a cause of floods.

Oswald, in 1889, stressed the importance of the relation existing between forests and floods. He said, "But the affliction of river floods in their chronic and infinitely more pernicious form is caused almost exclusively by the disappearance of arboreal vegetation, and especially by the destruction of the land-protecting highland forests."[1]

1. Oswald, F.L. (Lippincott's, 1889, v.44: p.239.)

Willey, in 1908, said that the investigations by the experts of the Geological Survey as well as the United States Forest Service proved beyond question that the floods of the rivers of the Southern States were due largely to the indiscriminate cutting of timber along their head waters.[1] Entire tracts of woodland forming the watersheds of some of the principal southern rivers had been stripped of their trees, so that the country was practically denuded of forest growth. The result of this was that the bare watersheds did not hold the rainfall and melted snow, the water flowing directly into the river channels and thus forming floods. The forest cover had acted like an enormous sponge, absorbing the precipitation of moisture, which gradually drained off. The work of the timberman had so stripped many of the watersheds that this sponge had been destroyed. The worst floods of North and South Carolina have been shown by an investigation to have been in watercourses from which the woodland has been thus removed. The connection between great floods and the destruction of the forests is very close as shown by the history of the Southern States; for prior to the inroads made by the timberman in the Appalachian, the volume of water coming down the rivers during the so-called flood season averaged far less in volume than it did after their coming.

1. Willey, Day Allen. (Scientific American, May 23, 1908, v.98:373.)

b. Belief against the destruction of forests as a cause of floods

The belief that forests have little effect upon floods is upheld by Moore and others. The observations made by competent engineers during two and one-half centuries in the basin of the Seine show that there has been a gradual and constant decrease in the height of floods with the diminuation of forests.[1]

Ernst Sanda, chief of the Hydrographic Bureau of the Austrian Government, has traced the history of the one hundred twenty-five floods of the Danube during eight hundred years, and concluded that progressive deforestation of the country has had no effect on floods.[2]

Mr. Moore studied the average stage and precipitation of the Ohio River from 1871-1908 and divided these years into two equal periods. There was a slight increase in precipitation for the second period that agreed precisely with the slightly greater average flow of water.[3]

1. Moore, Willis Luther. A report on the influence of forests on climate and on floods. Washington, D.C., 1910, p.19.

2. Forests in relation to climate and floods. (Scientific American, October 29, 1910, v.103:334.)

3. Moore, Willis Luther. op.cit. p.33.

The result of his investigation seems to prove that such deforestation as had taken place in the basin of the Ohio had had no appreciable effect on the flow of the river. Mr. Moore had Prof. H. C. Frankenfield, Chief of the River and Flood Division of the Weather Bureau, compile the data from one station on the Cumberland, three on the Tennessee, and five on the Ohio, and establish the average high water for the four wet months, January to April, and the average low water for the four dry months, July to October. He found that the average high water was no higher and the average low water was no lower for the last half of the period than for the first half.[1] We call attention to Zon's criticism of the reliability of statistics based upon the averages of river stages. He says,

"It has been pointed out that an average river stage cannot be a reliable measure of the actual discharge of the river. The water stages may decrease, yet the total discharge of the rivers may remain the same, as when the river beds are deepened or a change in the slope caused by river improvements takes place. Therefore, even if the height of the medium and low-water stages decreases, this does not furnish reliable proof that the total discharge has also decreased. The only way to determine with certainty whether a decrease in the volume of water has taken place is to measure directly, for a long period of years, the actual discharge of rivers and streams. It has been especially

1. Moore, Willis Luther. A report on the influence of forests on climate and on floods. Washington, D. C., 1910, p. 33-34.

emphasized that a diminished height of medium and low-water stages may be produced by an increase in the height of high-water stages, or, in other words, that the regimen of the rivers might undergo a change without a decrease in the total annual discharge."[1]

Lieut. Col. Edward Burr made a study of the flow of the Merrimac River in response to orders of the Chief of Engineers, U.S.A., for the purpose of determining what influence, if any, the forests exert upon the stream flow of the locality in question. There were available daily records of stream flow at Lawrence from 1849 up to 1909. His report bears the date of May 23,1910.

The conclusions of Col. Burr are quoted as follows,

"Deforestation of the basin(Merrimac River) continued progressively from the earliest settlements until about 1860 to 1870, and since that period, forested areas have increased through natural causes by 25 per cent or more of the entire basin, notwithstanding the continuance of lumbering operations.

"The average run-off through the river varies with the precipitation over its basin, and the percentage of run-off to precipitation is not appreciably affected by forest changes as great as 25 per cent or more of the basin.

"The frequency of floods has not been decreased by forestation, or increased by deforestation.

1. Zon, Raphael. Forests and water in the light of scientific investigation. p.53-54.

"Exceptionally high floods have occurred at intervals without respect to forest conditions."[1]

We must again call attention to the danger of taking the average run-off into account. The precipitation remaining the same, the average run-off may remain constant even though the high and low stages of the river may vary greatly.

Prof. Daniel Webster Mead made an exhaustive study of the available flow records upon the Wisconsin streams, particularly to determine the effect of the forest cutting upon the flow of the streams. He concluded, "That in general, the deforestation or cutting of timber in Wisconsin has had no material effect favorable or adverse, on the high-water, mean-water or low-water flow of the streams or on the regularity of such flow."[2]

C.W.Durham, Principal Assistant, U.S.Engineer, has covered the conditions in Wisconsin on the St. Croix and Chippewa Rivers relating to forests and the stream flow. Mr.Durham concludes,

"My conclusions are that the destruction of the pine forests in Wisconsin has had no effect whatever in creating or increasing floods and drouths in tributary

1. Alvord, John W. and Burdick, Charles B. Relief from floods. p.22.

2. Alvord, John W. and Burdick, Charles B. op.cit. p.24.

streams, or in the Upper Mississippi, inasmuch as these features are controlled by precipitation which has not increased or decreased to any marked extent, at least not during the periods of accurate observations made by the Weather Bureau. The high waters are not higher, nor the low waters lower than formerly, nor are they of greater frequency and duration, and the tendency appears to be of years favorable to navigation in both respects."[1]

Mr. Moore concludes his report as follows:

"(1) ------ Evidence is strong that the cutting away of the forests has had nothing to do with the creating or the augmenting of droughts in any part of the world.

"(5) Floods are caused by excessive precipitation---.

"(6) Compared with the total area of a given watershed, that of the headwaters is usually small and, except locally in mountain streams, their run-off would not be sufficient to cause floods, even if deforestation allowed a greater and quicker run-off. Granting for the sake of argument that deforestation might be responsible for general floods over a watershed, it would be necessary, in order to prevent them, to reforest the lower levels with their vastly greater areas, an impossibility unless valuable agricultural lands are to be abandoned as flood-producing areas.

1. Alvord, John W. and Burdick, Charles B. Relief from floods. p. 24.

"(7) The run-off of our rivers is not materially affected by any other factor than the precipitation.

"(8) The high waters are not higher, and the low waters are not lower than formerly. In fact, there appears to be a tendency in late years toward a slightly better low-water flow in summer.

"(9) Floods are not of greater frequency and longer duration than formerly." [1]

Lieutenant-Colonel H.M. Chittenden, of the engineer corps of the United States Army, discovered that the great floods of the Sacramento River were due to the sudden melting of soft snows which had been sheltered and conserved by the forests until late spring, and that the rivers on the east side of the range, comparatively bare of forests, though smaller, were steadier. [2]

c. Conclusions

The determination of the precise effect that a given area of forest within a large watershed has upon the discharge into the river cannot be obtained because so

1. Moore, Willis Luther. A report on the influence of forests on climate and on floods. Washington, D.C., 1910. p.37
2. Brooks, Benjamin. (Technical World, April, 1914, v.21:201.)

many other factors influence the behavior of streams. These other factors are the presence or absence of natural reservoirs in the form of lakes and swamps, the steepness of the slopes, the porosity of the rock and soil, and the nature of the climate.

"An inquiry among engineers regarding the influence of forest upon stream flow, made by the National Conservation Commission in the fall of 1908, showed that the majority of engineers in this country are of the opinion that forests affect the regularity of flow of water in streams. Of the 171 replies received from active, associate, and junior members of the American Society of Civil Engineers, 151, or about 89 per cent, mentioned rivers and creeks the regimen of which has changed to their knowledge after a reduction of the forest cover of the watersheds. Only about 20 replies were to the effect that personal observations upon the flow of water in rivers showed no direct connection between forests and stream flow.

"In Europe the effect of forests upon stream flow was pointed out by hydrographers as early as in the thirties of the last century."[1]

The part under forest will hold back little showers and postpone the rising of the rivers for a time, but it cannot prevent floods in the face of heavy, long-continued rains or the rapid melting of masses of snow. "Excessive

1. Zon, Raphael. Forests in the light of scientific investigation. p. 52.

rainfall and sudden thaws will always cause floods in rivers unprotected by large natural reservoirs like the Great Lakes."[1]

The run-off from some limited area during the spring flood period may be increased under certain conditions by the presence of a forest cover on a given watershed. Chittenden has shown that in Yellowstone Park and similar mountain regions the forests protect the snow from drifting, melting, and evaporating, while in the open there is much drifting and an early clearing up of those places well exposed to wind and to sunshine; therefore, when warm weather and its rain come on abruptly, and come on to stay for the summer, as they do in these regions, the melting of the snow in the forests, because of the greater area exposed, the surface being uniformly covered, is far more rapid than it is in the open where it is badly drifted, and leads to higher freshets and less enduring run-offs.[2]

A high-water stage follows when the capacity of a forest cover to retain moisture and retard run-off has been reached. If the forest had been cleared away and the bare soil exposed to frost, wind, and sun, most of the winter's snowfall

1. Shepard, Ward. (U.S. Dept. of Agriculture. Circular 19, p. 2.)
2. Moore, Willis Luther. A report on the influence of forests on climate and on floods. Washington, D.C., 1910, p. 16.

would have been dissipated and the freshet limited in volume largely to the immediate rainfall, little if any of which would have been retained by the frozen ground. The resulting flood, which would be much more flashy than from a forested watershed, might not reach even as high a stage and would be of very brief duration. An increase in flood flow caused by forest protection is the rare exception, and over a large area would be offset by beneficial results from other drainage units.

Zon summarizes the effects of forests upon stream flow which have been observed in this country and abroad as follows,

"1. The total discharge of large rivers depends upon climate, precipitation, and evaporation. The observed fluctuation in the total amount of water carried by rivers during a long period of years depends upon climatic cycles of wet and dry years.

"2. The regularity of flow of rivers and streams throughout the year depends upon the storage capacity of the watershed, which feeds the stored water to the streams during the summer through underground seepage and by springs. In winter the rivers are fed directly by precipitation, which reaches them chiefly as surface run-off.

"3. Among the factors, such as climate and character of the soil, which affect the storage capacity of a watershed, and therefore the regularity of stream flow, the forest plays an important part, especially on impermeable soils. The mean

low stages as well as the moderately high stages in the rivers depend upon the extent of forest cover on the watersheds. The forest tends to equalize the flow throughout the year by making the low stages higher and the high stages lower.

"4. Floods which are produced by exceptional meteorological conditions cannot be prevented by forests, but without their mitigating influence the floods are more severe and destructive."[1]

If it can be shown that erosion adds to the danger of floods by the deposition of silt on river bottoms, any method that will prevent erosion will lessen the danger of floods. Erosion as a result of deforestation is of importance, but of unequal importance in different sections. It is upon steep rough lands and impermeable soils that forests as an erosion-preventive factor are most important. In level countries it makes but little difference in this particular whether the ground is waste, cultivated, or densely forested. The effect of forests is relatively unimportant in regions composed of sand plains and gravel beds or strewn with lakes and swamps. If the soil becomes well sodded with grass, erosion is little worse in fields than in woods, but usually the fields are cultivated from time to time, and occasions come when the best of care and cultivation cannot prevent the formation of bad gullies that injure both the gullied fields and those of the lower grounds that are overflowed.

1. Zon, Raphael. Forests and water in the light of scientific investigation. p.69.

"The forest is the most effective agent for protecting the soil from erosion because (1) the resistance of the soil to erosive action is increased by the roots of the trees, which hold the soil firmly in place, and (2) at the same time the erosive force of the run-off is itself reduced; because the rate of its flow is checked and its distribution over the surface equalized."[1]

A well-kept forest has a dense ground cover of trees, shrubs, and lesser plants that impedes the flow of water. "Tree roots spread far and wide to a depth of 2 feet or more, usually much deeper than the roots of grass or farm crops; and the roots of the lesser plants help to bind the top soil together. On top of the ground is a mat of leaves or needles, twigs, branches, and dead grass and herbs, varying from a few inches to a foot or more in depth; and beneath this mat is the spongy woods mold or humus derived from the decay of generations of leaf fall.

"The canopy of leaves and branches breaks the force of rain and evaporates considerable quantities of it. The rain that penetrates the canopy has next to contend with the leaf litter, which retards the water in its flow over the surface, soaks up part of it, and passes part of it down to the humus and thence into the mineral soil. Also in their life processes, trees absorb large quantities of water from the ground and pass it off as vapor from their leaves. By these means the forest intercepts and evaporates

1. Zon, Raphael. Forests and water in the light of scientific investigation. p.41.

a part of the rainfall, absorbs another part, and slows down the surface flow of the rest, retarding its speed and erosion action on the soil. Even in heavy rains the soil under a dense well-kept forest is little disturbed, and the streams that derive their water from such a forest are likely to remain clear."[1]

The increase of erosion on watersheds that have been deforested has been observed frequently both in America and in Europe.

The annual silt of the Tennessee River is 11,000,000 tons; yet some of its heavily forested head streams carry only a trace of silt even in high water. The soil is gathered by the Tennessee River mainly from deforested and agricultural lands.[2]

Erosion in most of the region in Minnesota and Wisconsin which contain the headwaters of the Mississippi is not an important factor. The silt burden of the Mississippi River above Minneapolis is only one-fiftieth as great as that of the Tennessee River. The soil contains much sand and gravel, which absorb water readily even after the forest cover is destroyed. The land, moreover, is level or gently sloping; and the headwaters of the Mississippi have an extensive lake and swamp system, with a large capacity for storing flood waters.[3]

1. Shepard, Ward. (U.S.-Dept. of Agriculture. Circular 19, p. 5.)

2. Shepard, Ward. op. cit., p. 14.

3. Shepard, Ward. op. cit., p. 17.

Undoubtedly the greatest burden of silt and freshet run-off contributed to the Mississippi River comes not from forest land but from farm lands which are being unwisely used. This view is confirmed by reports on 6 major basins and individual reports on 73 drainage units. The silt and run-off is not only greater from the agricultural regions as a whole than from the forest regions - it could hardly be otherwise from a great basin only 20 per cent in area timbered - but greater in proportion to area.[1]

Europe furnishes us with numerous examples. A survey of the River Po by the government showed that floods had steadily increases in height for a century. The Loire was formerly much used for navigation, but is now no longer navigable above Saumur. The bed of the river is choked with sediment and in summer is only a stretch of sand. Only 13 per cent of the Loire watershed is forested whereas formerly the percentage was much greater.[2]

A good example of the effect of forest cover upon erosion and stream flow is furnished by France. In that country some 800,000 acres of farm land had been ruined or seriously injured as a result of clearing about the headwaters of streams, and the population of 18 departments was reduced to poverty and forced to emigrate. Forest

1. Sherman, E.A. (U.S.-Dept.of Agriculture.Circular 37, p.22.)

2. Shepard, Ward. (U.S.-Dept.of Agriculture.Circular 19, p.14.)

planting was begun on the headwaters of the streams in 1860. Up to this time 163 torrents have been entirely controlled by this means, and 624 more are beginning to show the effects of forests on their headwaters. A half century ago thirty-one of the torrents now entirely controlled by this means were considered hopelessly bad. After many experiments the foremost French engineers have come to the final conclusion that forest cover is one of the most effective means for checking erosion and that the best place to control stream flow is at the headwaters of the streams. Examples of reforestation of mountains for the control of torrents can be found in the French Alps and in Tyrol.[1]

The Weeks Act, passed in March 1911, provided that forest land which could be shown to exert an appreciable effect upon navigable streams might be purchased by the Government and created into forest reserves or national forests. The duty of determining this relation between the forests and the navigable streams was placed by the law upon the Geological Survey. Upon the passage of the Weeks Act, therefore, it devolved upon the Geological Survey to make a favorable showing on any and every tract of land prior to consideration of its purchase.

The Weeks Act approporiated \$ 11,000,000 in terms of fiscal years, \$ 1,000,000 for the first year and \$ 2,000,000 annually for the succeeding five years; these

1. Zon, Raphael. Forests and water in the light of scientific investigation, p.41.

amounts unless expended, lapsing with each July 1st.

Field parties from the Geological Survey during the four remaining months of the fiscal year from the passage of the act studied several large tracts of mountain forest land in the Southern Appalachians States and reported favorably upon them, based squarely upon the principle of protection of navigable streams from the products of excessive erosion due to deforestation and repeated burning of the forest mat or mulch. It was clearly shown that the silt and detritus resulting from such forest treatment was washed down into the tributaries and from them found their way into the lower navigable rivers and clogged them.[1]

Forests tend to prevent or decrease the height of floods by retarding the run-off. Moore writing in 1910 says, "At the tenth International Congress of Irrigation, held at Milan in 1905, papers were presented by representatives from France, Germany, Italy, Austria, and Russia, in which the writers heartily favored the protection of the forests and their cultivation. But these writers were unanimous in the opinion that forests exercise little influence upon either the high water or the low water of rivers."[2]

1. Mitchell, Guy Elliott. (Scientific American, Dec. 28, 1912, v. 107: 549.)

2. Moore, Willis Luther. A report on the influence of forests on climate and on floods. Washington, D.C. 1910. p. 19.

We may contrast this statement with that made by Zon[1] in 1927 in which he said, "----- the consensus of opinion among the leading authorities in engineering and forestry the world over is that the forest exercises a potent influence in the regulation of stream flow."

Such a divergence of opinion may be due to the complexity of the problem and the failure to give due weight to the factors involved, as well as to the needless confusion arising from the introduction of factors which have no bearing on the subject. Zon[2] says that with the exception of a carefully planned experiment by the Swiss Government and a similar experiment started in the Rocky Mountains by the Forest Service, no thoroughly accurate studies of this problem have been made anywhere.

The well-kept forest is the best water holder of the various forms of vegetative cover. The factors that make the forest a good soil holder also make it a good water holder.

It has been estimated by Ney that the amount of water which the forest cover saves to the soil by reducing the surface run-off and changing it to underground seepage is as follows: For forests at low altitudes when the rains are not heavy and the soil is less subject to freezing, 20 per cent; for forests of moderate altitudes, 35 per cent; and for mountain forests, 50 per cent.[3]

1. Zon, Raphael. Forests and water in the light of scientific investigation, p. 43.

2. Zon, Raphael. op. cit., p. 43.

3. Zon, Raphael. op. cit., p. 33.

The leaf mulch even in a prolonged rain keeps feeding the water underground and thus empties and refills itself. This absorptive capacity may be overtaxed in a violent or long-continued rain, but even so, the forest has already reduced the run-off and continues to impede the remaining surface water in its progress to the stream beds. Such torrents as rush from bare, gullied land are rare in a forest.

Underground storage of water by forests may be an important natural means of regulating and equalizing stream flow. The water carried into the earth by the absorbent ground cover of a forest may percolate for months before it emerges.

Humus and leaf litter also keep the soil itself mellow, porous, and more permeable. The soil of the forest is softer, lighter even than newly plowed loam.

A forest retards run-off by still other means. Water and snow, which falls on the leaves and branches of trees, are either evaporated or delayed in reaching the ground. The evaporated water may be as much as one-third of the total precipitation. The influence of forests in retarding snow melting is of more importance. A well-stocked forest exerts a modifying influence upon the extremes of temperature; it is warmer in winter and cooler in summer than open land. As spring comes on, snow melting may begin earlier in the woods, but it usually lasts from fout to

eight times longer than on open ground, depending upon the species, density, age, and location of the stand. The protection given the snow by the forest from the sun and wind and the partial retention of the spring rains by the forest cover prolongs the melting of the snow. Pine and hemlock prolong the melting of deep snows, even under warm rains, for several days longer than deciduous trees. As the mellow soil of a forest is likely to remain unfrozen or to freeze less deeply than soil in the open, it absorbs more of the snow water; soil in the open, freezing more freely and deeply during winter, permits snow water to rush off more rapidly into the streams. Even in midwinter after the ground in the open is frozen solidly, moisture from melting snow or rain can usually find its way through open spaces of the coarse top cover of forest litter into the protected layers below where it can be finally taken up by the soil. An important source of river floods are spring freshets from melting snow. Forests tend to reduce flood crests and to equalize stream flow by delaying snow melting, feeding part of the snow water into the ground, and thus prolonging the period of run-off.

The character of soil, the gradient, and the time, duration, quantity, and form of precipitation, as well as the character of the cover, all enter into the determination of the effect of forests on the amount of run-off. It is obvious that the ratio of total run-off to precipitation

will be greatest when the slope is steepest, the soil most impervious, and vegetation most scanty. The maximum run-off occurs at once in such a case.

The value of a forest in preventing erosion and regulating stream flow is not directly proportional to the volume of timber on any given area. The density of cover, amount and character of undergrowth, and depth of humus accumulation affect the value of the forest. The protective influence of a mature forest in open stand with a large amount of merchantable saw timber may be very low because of overgrazing or repeated ground fires which have destroyed the undergrowth and leaf litter. A watershed may be very well protected, on the other hand, by a young or scrubby growth or by thickets of inferior species by reason of the density of its canopy and the depth of litter accumulation.

Run-off is checked the greatest when the ground beneath is covered with an unbroken leaf litter. Run-off is little affected by a forest without leaf litter, on slopes at moderate altitudes.

The amount of surface run-off is greatly influenced by the porosity or permeability of the soil. Therefore, the influence of the forest will vary with the character of the soil on which it grows. The crowns of trees, which break the violence of the rainfall, together with a surface mulch of leaves and twigs, prevent heavy clay or other impermeable soils from becoming compact and allow

it to retain its granular structure, thus making it more permeable to water. The influence of the forest in decreasing surface run-off may be very insignificant on a soil very permeable to water, such as sand, consisting chiefly in preventing the soil from being washed away.

The effect of the forest on the amount of surface run-off varies with the geological formation, topography, and size of the watershed, as well as with the depth and character of the soil. The geologic formation and the dip of the strata are such in some basins that as much as 10 per cent of the precipitation is allowed to escape by deep underground passages and so entirely lost, at least to the given drainage basin.

The character of the flow in the stream is appreciably affected by the character of the stream and its tributaries, the slope or gradient of the stream, the presence of falls and rapids, the section of the stream, the arrangement of the tributaries, and the presence of natural storage reservoirs. The effect of the forest cover may be obscured or increased by them. The use of streams for irrigation or for water supply may also obscure the true effect of the forest on the regulation of their flow.

The Geological Survey failed to find any excessive erosion in the White Mountains due to deforestation. The Survey instituted hydrometric investigations on two small, almost exactly similar, drainage basins in an endeavor to

show that deforestation, and subsequent burning of the vegetal forest mulch resulted in a more rapid run-off, and therefore tended to make unstable the flow of streams.

One of the basins was largely clothed with virgin timber and the other was deforested and burned. It was shown by careful measurements of precipitation over the areas and of the run-off of the respective streams that not only was the snow held better in the forested area, but that during a period of 17 days in April, 1912, including three extended storms, the run-off in the stream in the deforested area was a comparative flood - practically double that of the stream flowing through the forested area.

The results of these studies are held to show that throughout the White Mountains the removal of forest growth must be expected to decrease the natural steadiness of dependent streams during the spring months at least.[1]

Zon summarizes the effects of forests in conserving precipitation as follows,

"(1) The hydrological role of forests in level countries differs from that of forests in hilly or mountainous regions.

"(2) In level country, where there is no surface run-off, forests, in common with other vegetation, act as drainers of the soil; hence their importance in draining marshy land and improving hygienic conditions. In such country their effect upon springs is unimportant.

1. Mitchell, Guy Elliott. (Scientific American, Dec. 28, 1912, v. 107: 550.)

"(3) In hilly and mountainous country forests are conservers of water for stream flow. Even on the steepest slopes they create conditions with regard to surface run-off such as obtain in a level country. Irrespective of species, they save a greater amount of precipitation for stream flow than does any other vegetable cover similarly situated. They increase underground storage of water to a larger extent than do any other vegetable cover on bare surfaces. The steeper the slope the less permeable the soil, and the heavier the precipitation the greater is this effect.

"(4) In the mountains, the forests, by breaking the violence of rain, retarding the melting of snow, increasing the absorptive capacity of the soil cover, preventing erosion, and checking surface run-off in general, increases underground seepage, and so tend to maintain a steady flow of water in streams."[1]

9. Over-grazing

Each individual drainage unit which embraces any considerable acreage of unreserved public domain suitable for grazing is reported, with very few exceptions, as being injured by overgrazing and unregulated grazing, with destructive erosion taking place over large areas. There are no data available to show to what extent this results in increasing the rapidity of the run-off. Except for local

1. Zon, Raphael. Forests and water in the light of scientific investigation. p.40.

freshets, from a flood standpoint, such increase would not be material. The aggregate of the burden of silt which misused grazing lands contribute to the Missouri and Arkansas must be very great.

The acreage is slowly dwindling because these lands are open to entry under the various public land laws. The report of the General Land Office of the Department of the Interior, July 1,1926, gives the total area of public lands in the Mississippi Basin as 32,514 square miles, or 22,808,960 acres. Although some of these lands are timbered, they practically all have some value for grazing. The watershed of the Missouri River contains most of these lands - 31,084 square miles. 1,410 square miles are on the Arkansas watershed; and 20 square miles are on the Red River.

These lands should be controlled. It is not ignorance or lack of interest that accounts for misuse but lack of control. No stockman has an incentive to avoid overgrazing the public range when the leaving of any unused forage plants for reseeding is almost certain to result in some other stockman driving in his stock and feeding off what has been so painstakingly saved.

Grazing control in the national forests has as one of its aims the reduction of erosion and flood discharge. Similar grazing control of the unreserved public domain has been recommended by the Secretary of the Interior.

An important phase of grazing control is the building up of an herbaceous cover in order to ameliorate floods and silting. The result of an experiment by the Forest Service on open grasslands in Utah showed that the run-off from rainstorms on overgrazed land was seven times as great as that on moderately grazed lands.[1]

The Breaks of the Southwest present a serious erosion problem. This region marks the boundary or break between the staked Plains of the Texas panhandle and the lower rolling red prairie country to the east. A rock cap which underlies the plains and preserves their surface until undermined and broken off forms the steepness of the escarpment between the lower edge of the Breaks and the High Plains.

The soil of the High Plains almost entirely soaks up the rain which falls upon it. The Breaks, which extend back along the valleys being cut by the upper tributaries in Texas and western Oklahoma, receive the run-off, and consequently the erosion.

A combination of many steep slopes, scanty vegetation, abundance of easily eroded soil, and sudden hard rains, makes soil erosion extremely active through the Breaks region. The Arkansas and the Red Rivers draw their first great burden of silt from this region, and it is this source of silt which the population of those two great drainage basins reckon with in their plans for development, including the

1. Shepard, Ward. (U.S. Dept. of Agriculture. Circular 19, p. 14.)

storage of water in reservoirs for irrigation, power, municipal supply, or other purposes. The storage capacity of reservoirs in that region will be diminished very rapidly unless the burden of silt carried by the local streams can be greatly reduced.

The method of stopping erosion in the Breaks region is a problem for research, but meanwhile overgrazing is accelerating the progress of erosion.

The Manti National Forest in Central Utah affords an exceptionally good illustration of the harmful effect of overgrazing upon stream flow. Severe floods after all storms of more than usual violence have occured in this region for a number of years. This condition of erratic run-off was shown, by a careful study made during the spring and summer of 1910, to have followed heavy overgrazing in the mountains, and that where grazing had been restricted the conditions were rapidly improving. The towns located along the base of the Wasatch Range are vitally interested in securing an equable stream flow. They are not only dependent upon the streams for their water supply, but they have also suffered heavily from floods in the past and are still constantly in danger.

A committee in 1910 composed of two sheepmen, two cattlemen, and a merchant, representing the towns of Orangeville and Castledale and surrounding agricultural settlements in Emery County, expressed the belief that floods

were due mainly to the denuded condition of the range which had resulted from overgrazing, and requested the protection of these watersheds. They stated, in support of their request, that for many years after the settlement of Castle Valley in 1878, floods were unknown. However, soon after the ranges on the heads of the streams were heavily stocked with sheep and cattle, freshets began to occur with each heavy rain during the summer months, and these have steadily increased in volume and destructiveness.

Inquiries made of a number of men in the Forest showed that no serious flood had occurred in any canyon prior to 1888, at which time the sheep business had been in operation for about six or seven years and the range was already becoming badly depleted. Floods have occurred frequently in one part or another of the Forest since that year. The last serious flood in Manti Canyon occurred in August, 1902, before any effort was made to protect it from overgrazing. All stock were excluded from the uplands during the years 1904 to 1909, and the Forest had a chance to become well reclothed with vegetation before the bad flood season of 1909.

In August, 1909, the beneficial results obtained from the protection afforded Manti Canyon were forcibly shown when Ephraim and Six Mile Canyons were flooded severely, while Manti Canyon lying between them, was not perceptibly affected. Ephraim and Six Mile Canyons were heavily over-

grazed by sheep from 1882 until the establishment of the Forest in 1903, and had since been closely grazed by cattle. Accordingly there was a much better soil cover in Manti Canyon, and there seems to be no reasonable doubt that to this fact it owed its escape from the floods of August 17 and 31, 1909.

On September 18 and 19, while Ephraim Canyon was flooded twice and Manti Canyon had no flood, the latter canyon was easily handling the run-off of a volume of water approximately 25 per cent greater than that which was rushing from the Ephraim watershed.

Reynolds says, "Taking all the facts into consideration the absence of floods in the Manti Canyon can be attributed only to the protection afforded by the excellent crop of forage on the area closed to grazing. The growth of grass and weeds in the bottoms of the gullies and on the slopes was sufficient to delay the run-off until the water soaked in, while at the same time the earth was not so completely trampled by the constant traveling of stock as in the other canyons."[1]

Provision has now been made to protect the watersheds from further damage by making a reduction in the number of cattle and sheep which will be allowed to graze upon upon the Forest.

1. Reynolds, Robert V.R. (U.S.-Dept. of Agriculture. Forest Service. Bull. 91, p. 9.)

10. "Blowing up" of the ground on the land side of a levee

The effect of the external pressure of water, transmitted through or by a loose and weak underground, may be to "blow up" the ground on the land side of the levee, or, roughly speaking, knock the bottom from under it.

It is supposed that the five breaks which occurred in the Lower Yazoo District of Mississippi, in 1890, proceeded from this cause, as well as the accident to the St. Louis settling basins. A masonry wall 8 ft. thick and 15 ft. high rested on a concrete foundation 15 ft. wide, and was built on a soil of river silt composed of sand and mud. This wall separated two settling basins, one full, the other empty. Prof. Johnson said, "Evidently the seepage from the full basin found its way beneath the puddle in the empty basin, and raised it, with its covering of concrete, over an area of about 100 feet square, like a great blanket, until it burst through and washed out a hole beneath the stone wall."[1]

11. Other factors determining floods

Other factors determining floods, more or less intimately related, may be classified under precipitation, size of watershed, and climate.

1. Starling, William. The floods of the Mississippi River. p. 4.

a. Precipitation

(1) Seasonal distribution

It is needless to say that without precipitation there would be no floods. Flood conditions reappear every spring in some noticeable way. Floods do not occur because the rain is so much heavier, or that the quantity of snow on the ground is great, but that whatever does fall is in a large measure converted into river water.[1] The time of a flood is of importance to the planter in the Mississippi Valley. The water which percolates through the soil, the "Seep-water," as it is called, is a serious injury to the planter. In the Mississippi Valley seep-water is regarded as far more hurtful than rain-water. It is very difficult to get rid of it by ditching. It may go out of the ground in time to make a crop if the flood comes early in the season. The seep-water will kill whatever it touches except grass if the flood comes late, and then it will be too late to replant.

Fortunately for the planter the influence of seep-water does not extend very far from the river, and as it does not injure Bermuda grass, the riparian lands may be used as pastures or meadows.

(2) Intensity, area, duration, and direction of storms

The intensity, duration, direction, and area

1. Starling, William. The floods of the Mississippi River. p. 31.

covered by storms have an important bearing upon flood heights. Excessively heavy or long-continued rains cause high floods in large navigable rivers.[1]

The severity of the Mississippi flood in 1927 was due largely to the run-off from heavy and prolonged rainfall in the lower central valley.[2]

Rain-storm after rain-storm during the months of April and May, 1912, caused the Mississippi to swell, undermine dikes, and break new crevasses all the way from Vicksburg to New Orleans.[3] The storms which originate in the Gulf itself are the most formidable of all storms in the Mississippi Valley, so far as rainfall and floods are concerned.[4]

Gulf cyclones are generally marked by deluges of rain, which last is not merely caught by the mountain ranges that intercept and, as it were, strip the clouds, but also falls in profusion on all parts of the lowlands that lie in the track of the storm. The passage of one of

1. Zon, Raphael. Forests and water in the light of scientific investigation, p.66.
2. Sherman, T.A. (U.S.-Dept. of Agriculture. Circular 37, p.4.)
3. Marshall, Logan. The true story of our national calamity of fire, flood and tornado, p.301.
4. Starling, William. The floods of the Mississippi River, p.26.

these cyclones often occupies two or three days, and a rainfall of three inches is not unusual. A considerable flood has been known to result from two of them, at an interval of about a week apart. The time was from the 26th of March to the 2nd of April, 1886. There was little snow on the ground, and the rivers were decidedly low.

General heavy rains of considerable duration occasion the floods of the great rivers like the Mississippi and the Ohio, particularly if they fall upon melting snow, or if the run-off reaches the main water courses at a time coincident with the run-off from the melting snows. A series of great storms more or less local may also cause floods on such rivers, particularly if the storms occur at such times and places that the run-offs coincide in the main stream. The great floods of 1913 upon the Mississippi and Ohio Rivers were caused by an unusually excessive storm, on March 24th and 25th, extending principally across the northern tributaries of the Ohio.[1]

It is difficult to define the rainfall in terms of its effect upon the flow of streams, for the greatest rainfall in a given time does not always produce the greatest flood.

The height of a flood is influenced by the condition of the ground as to moisture when the decisive rain occurs. The soil may be already saturated with previous rains or with melted snows, so that it will not easily

1. Alvord, John W. and Burdick, Charles B. Relief from floods, p. 11.

absorb any more, and this independently of season.

Floods of less magnitude but more closely confined may reach heights not attained by floods of greater magnitude whose waters have been allowed to spread over the lowlands. Breaks in levees will lower the flood heights in the main channel.

On small watersheds, a short, sharp storm may produce a great flood. A short, sharp storm lasting only four hours, falling upon a watershed of 12.9 square miles caused the disastrous flood of Erie, Pa., in 1915.[1]

Heavy precipitation is one of the factors favoring the occurrence of floods in the streams flowing from the Manti National Forest.[2]

(3) Precipitation as snow

A sudden thaw which dumps simultaneously an accumulation of snow, which has fallen over a wide area into the rivers which drain it, may produce a flood, but the principal cause of floods is not the melting of the winter's ice and snow. It is well known in the case of the Ohio that some of the greatest floods ever recorded have occurred when there was little snow on the ground. Some of the heaviest snowfalls, on the other hand, have disappeared by gradual thawing, without rain, and made but a trifling and evanescent impression on the rivers. The

1. Alvord, John W. and Burdick, Charles B. Relief from floods, p. 12.

2. Reynolds, Robert V. R. (U. S.-Dept. of Agriculture. Forest Service. Bull. 91, p. 16.)

action of snow should not be excluded when it exists. It cooperates powerfully with the rain. The effect of a warm and heavy rain is greatly augmented by deep snow passing off with it, that too, at a very critical time.[1]

b. Watershed

(1) Size

In order to produce a flood we must have an accumulation of water falling over a considerable area, and then condensed at one point. Three rivers draining a considerable part of seven counties meet at Dayton, Ohio; Cairo, Illinois, is the meeting place of all the waters from about eighteen states.

It is obvious that ordinarily more rain will fall on a large drainage basin than on a small one. The same amount of rain falling on two drainage basins, one large the other small, may not produce a flood in the large one, while the other one is flooded. A tributary of a large drainage basin may be in flood, while the main channel shows no appreciable increase in height. The destructive power of a flood may be increased more by a single gully of less than a quarter of an acre than it is by the clear run-off of an entire section of well-managed fields or woods. The size of the watershed, therefore, has an important effect upon the rate of flood run-off.

1. Starling, William. The floods of the Mississippi River, p. 25.

(2) Shape

The shape of the watershed also affects the flood rate. Thus, if a watershed is long and narrow, it may have a less unit flood run-off than if it should be more nearly circular in form, particularly when, in the latter case, the tributaries radiate fanwise from the border of the drainage area, thus tending to bring the flood waters simultaneously to one place. In the long and narrow drainage area it often happens that the drainage from the downstream watershed passes away before the waters from the upper tributaries reach the lower parts of the drainage area.

(3) Topography

The surface topography is a very important contributing factor. The water from the flat prairie lands of Illinois is slowly drained away in a great storm. The fields become detention basins contributing the water slowly to the wide flat valleys of the minor streams, which in turn give up their water slowly to the principal rivers. The roof-like hillsides of Pennsylvania, the Appalachian region, some parts of Ohio and other places in the Middle West deliver the rainfall so rapidly to the main streams that heavy storms of comparatively short duration may produce excessive flood rates.[1]

Both the valleys of the Mississippi and the Miami, particularly, are veined with streams tributary to the

1. Alvord, John W. and Burdick, Charles B. Relief from floods, p. 13.

rivers, and in times of flood the water rises with amazing rapidity and spreads far and wide over the valley floor. The depth and extent of the floods at Dayton is accounted for by the fact that the city lies in a level region and that there is not enough pitch to the land below to carry off the water.[1] Many floods have occurred at Dayton.

The portion of the Wasatch Range which composes the Manti National Forest consists of alternating layers of white limestone and sandstone, with little or no rock of volcanic or igneous origin.

The soft and coarse sandstone is readily eroded, and deep gorges formed after the limestone layers have once been completely cut through. The canyons are unusually steep as a result of this action. Rapidity of run-off is greatly increased by this steepness of slope, as well as the danger of floods and damage from erosion.[2]

(4) Surface and subsoil

The rapidity of run-off is greatly affected by the character of the surface and subsoil, as to its quality of shedding the rain or absorbing it. As floods are created only by actual run-off, each factor that adds to the amount of run-off also adds to the danger of flood. Upon the lower Peninsula of Michigan, we have an example of highly absorptive

1. Marshall, Logan. The true story of our national calamity of fire, flood and tornado, p. 317.

2. Reynolds, Robert V. R. (U. S.--Dept. of Agriculture. Forest service. Bull. 91, p. 11-12.)

surface, gentle slopes and a deep and capacious subsoil of sand and gravel. In some localities all the rainfall is absorbed by the surface.

Such watersheds as the Scioto and the Miami in Ohio, upon the other hand, are largely underlaid by rock at no great depth. The surface soils, although often of a gravelly nature, are interspersed with clay to such extent as to be highly impermeable and comparativelt non-absorbent. Throughout the major part of the Ohio River watershed similar conditions exist generally, and except for its great size, the unit flow rate would be excessive.

The soil of the Manti National Forest, Utah, consists mainly of sandy loams of various degrees of fineness, often mixed with calcareous gravels. Such a deep soil in fairly level country and with a good ground cover would absorb water quite readily and would tend to equalize the run-off. However, in this particular region because of steep slopes and lack of ground cover, the soil is very easily eroded and in many places is only a few inches deep.

Silting is a menace to the engineering works used in river control. The storage capacity of reservoirs built for flood retention is reduced by silting, and they may be ultimately filled by this action. Brooks, writing in April,1914, tries to show that floods are due to the deposits of silt on river bottoms taken from farm lands. He makes the statement that reclamation engineers are all

agreed that the bottoms of all our rivers running through farming country are rising. If the depth of a river is decreased by a deposit of silt on its bottom, the width of the river must be increased to carry the same amount of water. If the width of the river is not increased, the stream will overflow its banks.[1]

The Colorado River is a constant menace to Imperial Valley, California. The control of this river is largely a problem of silt control. Imperial Valley contains 450,000 acres of irrigated farms and populous cities. It lies in a great depression or sink from 100 to 300 feet below the channel of the river. The slope toward the gulf is less than the slope toward the valley. The river at any flood time may break from its shifting and uncertain channel and turn into the valley. The valley will be permanently inundated if the Colorado once breaks into the valley and is not returned to its channel, because there is no outlet for the water.[2]

The river flows virtually upon the rim of the great basin in which the Imperial Valley lies and is confined in its course by levees running south from the international line at Andrade for many miles and then east to Volcano Lake. The expense of the levees is a serious burden which must be borne ultimately by the land served

1. Brooks, Benjamin. (Technical World, April, 1914, v.21: 198-204.)

2. Smith. Boulder Canyon Project. Wash., D.C., March 15, 1928. (U.S.-House of Representatives. Report No.918.p.15-16.)

with water. Levees have given only partial protection to the valley. For the six years, 1921-1926 inclusive, the average expense per year under the head of river protection was $ 202,083.[1] In 1905 the river took advantage of the temporary intake provided for the Imperial Canal and the entire stream poured its flow into Imperial Valley for a period of 18 months. Only by great effort was the break closed and the river returned to its channel. The United States then built Ockerson Levee in Mexico at an approximate expense of $ 1,000,000. It was washed away almost as soon as it was completed. The river now turned westward toward the Volcano Lake region, still in Mexican territory, but in a lower depression on the delta. The people of Imperial Valley built an extensive levee system to keep the river in this course. This depression filled up gradually. Pescadero Cut was then made by the Imperial irrigation district at a cost of approximately $ 700,000, to direct the river into a triangular depression lying between the old river channel on the east and the Volcano Lake region on the north and west. This is the last depression on the surface of this delta into which the river can be directed.

1. ---Development of the Lower Colorado River. Wash.,D.C., 1928. (U.S.-Dept.of the Interior-Bureau of Reclamation. p.384.)

W.F.Durand[1] says, "------,it is clear that the presence of silt gives rise to danger, expense, and future menace as follows:

"1. Building up the general level of the delta cone with danger of flooding Imperial Valley.

"2. Expense in maintenance and continued extension and elevation of levees.

"3. Expense to Imperial irrigation district in clearing its canals of silt.

"4. Expense to farmers in valley in caring for silt deposited on land.

"5. Expense to the entire valley in the filtration of all water for domestic and municipal use.

"6. Menace in gradual elevation of land and in consequent reduced gradient between point of diversion and the land served, with consequent choice of either accepting reduced flow of present canals or of going to expense of enlarging cross sectional area.

"7. Menace to land of becoming choked and relatively impervious from deposition of fine silt, of which the material carried on to the land is chiefly composed."

1. ---Development of the Lower Colorado River. Wash.,D.C., 1928. (U.S.-Dept.of the Interior-Bureau of Reclamation. p.384-385.)

Stewart[1] says that the basic cause contributing to the flood situation on the Mississippi River today is the soil erosion taking place from farm land in the Mississippi drainage area. Land in this region is now largely under cultivation, whereas 125 years ago it was under sod. In Iowa and Illinois, for example, 85 per cent of the entire area is now improved farm land. Soil erosion is taking place at an alarming rate as a result.

The faulty system of agriculture in the Mississippi drainage basin does not permit the soils to hold the rainfall as of yore, but lets the soil slip slowly to the sea.

It has been calculated by the National Conservation Congress, on the basis of estimates from 30,000 farms, that 16,597 square miles of farm land have been abandoned in the United States due to soil erosion. The entire cultivated area of England is equal to this area. There is a rapid and abundant run-off from it. Large areas which were formerly good farm land are now covered with deep gullies. In the comparatively level corn-belt soil sheet erosion is even now very active, and is promoted by the finely divided clay soil and the clean cultivation practised in corn culture.[2]

"The extent to which soil is eroded depends upon the climate, steepness of the ground, the character of the soil, the geological formation of the region, and the surface cover. When the slopes are steep, the soils and the

1. Stewart, Robert. (New Republic, Dec. 7, 1927, v. 53:65.)

2. Stewart, Robert. op. cit., p. 66.

underlying rock friable, the rains torrential, and the surface bare of vegetation, erosion by surface run-off reaches colossal proportions. In such regions thousands of acres of fertile soil are destroyed each year and millions of cubic feet of silt deposited in the bottom of rivers to form bars and shoals which change the regimen of the streams and obstruct navigation."[1]

While not diminishing the importance of soil erosion, we must not leave out of consideration the other factors that determine floods.

(5) Lakes, ponds, and swamps

The storage of water in lakes, ponds and swamps has an important effect upon floods. Shepard[2] and Alvord and Burdick[3] mention the uniform flow of the St. Lawrence which is regarded as one of the best-regulated rivers in the world because of the storage system afforded by the Great Lakes. Streams which are fed by lakes show a similarity in flow depending upon the extent of the water areas in comparison with the total watershed. Lakes, ponds and swamps, however, constitute upon most of our streams a very small part of the tributary drainage area.

1. Zon, Raphael. Forests and water in the light of scientific investigation, p. 40-41.
2. Shepard, Ward. (U.S.-Dept. of Agriculture. Circular 19. p. 4.)
3. Alvord, John W. and Burdick, Charles B. Relief from floods, p. 14.

A correspondent[1] to the Scientific American of May 3,1913 expressed his belief that the drainage of swamp land would cause a rise in the water of the Mississippi which would make necessary higher levees.

In the case of small streams flowing through extensive swamps the flood waters are held back, but observations and measurements on the Mississippi show that swamps do not reduce the height of floods on that river.

"Before any of the great floods reach their highest limit, these swamps discharge as much water into the river at their lowest limits as they receive in the proportion above. These observations are the foundation of the following conclusions of Humphreys and Abbot:

"Swamps do not reduce the height of floods above or below but they do retard the rise and the fall of the river below and increase the duration of floods, and they also reduce the height of floods along their borders."[2]

(6) Vegetation

The character of the vegetation is a factor in preventing run-off and increasing the absorbent capacity of the soil. We have already discussed the harmful effects of overgrazing in the Manti National Forest, Utah(p.46), and the result of the destruction of the sod of the Mississippi drainage area(p.61). Grass breaks up the stream

1. Cross,A.N. (Scientific American,May 3,1913,v.108:397.)

2. Robbins,Arthur G. Discussion of the methods employed for the control of rivers and the prevention of floods,p.20.

of water, restrains its speed in running off, and binds the earth in place.

Tufts of Bermuda grass are placed on the levee after the completion of the work. It is a jointed grass which puts out lateral runners, like a strawberry vine, and under favorable circumstances rapidly covers the ground. It attains its best growth in loamy soil, or soil with a moderate proportion of sand. It does not do well in pure sand or pure clay. Moisture is needed to start it properly, but after it is well matted it will stand drought, freezing or submersion for weeks. It is a good defense against the wash of ordinary waves if the slope is flat and the soil is moderately strong. It affords protection against rain with sandy material, but not against even moderate storms when there are no woods or other cover in front of it.[1]

As the size of the river channel diminishes the effect of drift, willows and aquatic vegetation becomes increasingly important and very seriously impairs the delivery from such artificial channels as main drainage ditches.

It has been observed even upon the larger streams where a large part of the flood cross section is upon land that the flood slope and height is considerably increased where the bottom lands are covered with trees and underbrush as compared to the more open or cleared lands. According to the report of the U.S.Department of Agriculture, channels

1. Starling,William. The floods of the Mississippi River,p.7-8.

obstructed by vegetation and drift have been an important cause of flood heights in the Marais Des Cygnes Valley in Kansas. The snags, brush, and gravel bars resulting from these obstructions in the river channel are said to be an important contributing cause to the flood heights in the Neosho Valley, Kansas.[1]

The vegetative cover which has received the most attention is that of the forest. The forest tends to prevent floods by decreasing the run-off and increasing the absorbent capacity of the soil, and by preventing erosion. The influence of forests in decreasing the run-off and preventing erosion has already been treated in detail under the destruction of forests as a cause of floods (p.20).

(7) Works of man

The works of man may have an important influence upon flood heights, particularly in the smaller streams. Man has influenced the character of the vegetation. Agricultural land absorbs the rainfall rapidly up to a certain depth and some forms of vegetation, particularly the meadow and grain field, possess the ability temporarily to store considerable water. The influence of vegetation except heavy brush is slight in the barren season of the year, and frozen fields will shed the water readily. Man's handiwork is found in the drainage of the swamps through the

1. Alvord, John W. and Burdick, Charles B. Relief from floods, p.99.

construction of ditches, the improvement of the river channels and through the tile drainage of land. The prairie states of the Middle West have practised this very extensively. The drainage of lakes and swamps that were capable of storing a considerable depth of water has tended to increase the stream flows in the wet season and diminish the flow in the drough. Ground that is permanently wet, upon the other hand, cannot absorb rainfall, and therefore the drainage of the swamps and the lowering of the water table sufficiently to permit of agriculture has created an underground reservoir that did not exist in the state of nature[1].

The construction of a barrier across a river is always a source of danger to the valley below. We have already noticed the results of the collapse of dams (p.17). Reclamation of farm lands by levees has had an important effect upon the flood heights of the Illinois River, and to a slight extent upon the maximum flood flow on account of the river-valley storage that has been destrayed by the reclamation of the farm lands. The encroachments of the cities have had an effect upon flood heights. Railroad embankments and bridges in some important instances have raised flood heights by the reduction of the channel cross-section of the river.

The lower Hudson, the upper Mississippi and the Potomac are typical of streams that have caused flood damage[2]

1. Alvord, John W. and Burdick, Charles B. Relief from floods, p.14-15.

2. Morgan, Arthur E. (Scientific American Supplement, Dec. 19, 1914, v.78:394.)

because they were encroached upon.

In very many cases the obstruction of channels has had much to do with flood damage, and the need for effective supervision to prevent further obstruction is becoming more and more urgent. Most European states now exercise strict control of river channels, but European cities are still suffering for the sins of the past.[1]

c. Climate

(1) Freezing as arresting flow

The temperature of the region may have an important bearing on flood heights. Zon says,

"On the whole, the amount of water carried by a river depends upon precipitation and temperature. It is greater when the temperature is low, though the precipitation is scant, than during the years of greater precipitation but of higher temperature. Large rivers are least affected by climatic fluctuations, because their larger watersheds exercise an equalizing influence upon the ununiform distribution of precipitation. That the flow of water in streams depends largely upon climate is now a fact accepted by meteorologists, engineers, and foresters, and is supported by very careful observations on a number of rivers, especially in Europe."[2]

1. Morgan, Arthur E. (Scientific American Supplement, Dec. 19, 1914, v. 78: 394.)

2. Zon, Raphael. Forests and water in the light of scientific investigation, p. 58-59.

Greenleaf says that the primary causes of floods are the variation in the intensity of the rainfall and of temperature through the successive seasons of the year. He gives the time of flooding of the tributaries of the Mississippi as it is determined by temperature and rainfall. The determination of the exact time the Mississippi will be in flood is impossible because temperature and rainfall varies on its tributaries from one season to another.[1]

All flow may be temporarily arrested if freezing weather is very excessive, and when the cold is sufficiently continuous the climatic influence is very important in the accumulated snow blanket and its sudden release upon the approach of warm weather, particularly if accompanied by rain. The heavy formation of ice in the rivers of the North exercises an important influence upon flood heights, particularly on account of gorges in that season of the year when the ice may be broken up and floated away by spring rains.

(2) Freezing as affecting ground surface

Freezing decreases the absorbent capacity of the soil. Frost destroys much of the vegetation and covers even the most open porous soil with a more or less impenetrable coating. Any covering of vegetation tends to retard run-off and its destruction accelerates it. A given storm on any watershed will produce a greater flood in the barren and frozen season of the year.

1. Greenleaf, J.L. (Engineering, March 1897, v.12:949-958.)

Probable Decrease or Increase of Floods

Moore quotes from Col.H.M.Chittenden,M.Am.Soc.C.E., volume 34,page 944, Proceedings of the Society of the Civil Engineers, as follows, "The constantly reiterated statement that floods are increasing in frequency and intensity, as compared with former times, has nothing to support it. There are, it is true, periods when floods are more frequent than at others,------, but, taking the records year after year for considerable periods, no change worth considering is discoverable----."[1]

Moore believed that floods were not of greater frequency and longer duration than formerly.[2]

A question addressed to the Department of the Interior as to the probable increase or decrease of floods brought a reply from the Geological Survey saying that destructive floods had taken place at all times and that there was not sufficient data available in regard to them to determine whether they were on the decrease or increase.

Preventive Measures

All means for reducing the rate of flood flow are included in works for flood prevention. The reservoirs or

1. Moore,Willis Luther. A report on the influence of forests on climate and on floods. Washington,D.C.,1910.p.19.
2. Moore,Willis Luther. op.cit.,p.38.

detention basins for the purpose of storing flood flows and feeding the water gradually to the streams are placed in this class. Where it can be shown that reforestation would have an influence upon flood flow, it is included in this group.

1. Reforestation

Reforestation has been practised in different countries of the world. France and Switzerland have planted trees near the sources of their mountain streams.

a. Determining factors

There are certain factors which determine the reforestation of any given area. Some of these factors will be considered below.

(1) Source of a pure water supply

The problem of obtaining a pure water supply is a vital one which concerns every town. Ashe[1], writing in 1909, recommended that Pittsburg and her satellite towns obtain water in the forest-protected mountain streams. Pittsburg and the surrounding towns had been obtaining their water supply from rivers and tributaries which were contaminated by the sewage of towns and villages higher up the rivers. The Boston Globe of Dec. 13, 1928, contained an account of how Winchester, Mass. had solved her water problem by planting 300,000 evergreens on the watersheds around her three reservoirs.

1. Ashe, W.W. (Charities, Feb. 6, 1909, v. 21: 828.)

(2) Immediate cost

Hitherto the cost of purchasing a forested watershed and holding it as unproductive property has deterred cities from seeking such sources. That difficulty no longer exists. Forest lands have now a recognized and constantly increasing earning power. If a watershed is purchased at a reasonable price and is well managed, it will become, as stumpage further appreciates in worth, a valuable municipal asset. Or if a town is small and unwilling to assume the responsibility of such management, it can well cooperate with the state in developing a system which will secure to it pure water, and at the same time preserve to the state the earning power of its forests which are among its most valuable natural resources.

Winchester, Mass. obtained the trees which she planted on the watersheds around her three reservoirs from the State Department of Forestry at an average cost of a cent apiece, and the labor cost of setting them has averaged about three cents per tree. Winchester expects that the wood cut and sold from the watersheds will in the future reimburse the town for its investment.

To meet the need of cheap planting stock the Clarke-McNary Act authorized Federal cooperation with the states in growing and distributing planting stock to farmers. The 32 cooperating states are producing about 60,000,000 trees a year, of which about half are set out on farms.[1]

1. Shepard, Ward. (U.S.-Dept. of Agriculture. Circular 19, p. 22.)

The Clarke-McNary Act at present appropriates $ 75,000 a year for aiding timber planting on farms, and Sherman[1] credits it with stimulating the planting on farms of 30,000 acres during 1926, which would not have been reforested without this contribution.

(3) Length of time for growth

A forest is not an immediate means for flood relief. If destructive floods need to be prevented at once, the remedy must be found in some other means than reforestation. It takes some time for a forest to exert its influence. Sherman[2] has estimated that successful forest planting in the Mississippi Valley would in 5 to 10 years reduce the average annual loss by erosion to a negligible factor.

(4) Future value

The future value of a forested region will be a combination of its beneficial results. It is expected that a forest by the sale of its timber some time in the future will help to pay the original cost of its planting. The forest prevents erosion, increases the moisture-holding capacity of the land by leaf-litter accumulation, increases the permeability of the soil, and prevents the silting of streams.

1. Sherman, E.A. (U.S.-Dept.of Agriculture.Circular 37,p.36.)

2. Sherman, E.A. op.cit.,p.36.

2· Reservoirs or detention basins

No large detaining basins have been built in the United States so far as known primarily for flood protection although a great many storage reservoirs have been built· There are a large number of reservoirs which serve as municipal water supplies· The streams have been dammed for the purpose of obtaining water-power, and the ponds thus created have been used also to store water in time of plenty to be used in drought, or to store water from hour to hour to be used according to the demand for power·

Europe on a small scale has used storage reservoirs for a variety of purposes· Reservoirs, in the United States, so far as known, have been designed for one specific purpose, such as water storage or water power, and the other benefits have been merely incidental· Navigation has been improved by a number of reservoirs, including the reservoir system at the head of the Mississippi River, the greatest artificial reservoir system in the world· A detention basin is designed primarily for flood prevention and not for water storage except in case of flood· It may be defined as a dam across a river valley having in its base an opening of such predetermined size that in the case of a great flood, the water ponds up behind the dam and is re-delivered to the stream only so fast as the opening provided can carry it· It would be practicable to reduce the flood to any rate desired with a detention basin of sufficient size, and an opening sufficiently small·

It has been recommended that the reservoir to be constructed in Boulder Canyon on the Colorado River in Arizona-Nevada be made of such capacity that it will act as a desilting reservoir. The river receives almost all of the silt now being discharged through and above the canyon section and above Boulder Canyon.

If 125,000 acre-feet of silt is deposited annually in a reservoir in the canyon section of the river, a storage capacity of 7,000,000 acre-feet would provide for a silt accumulation of well over 50 years. It is expected that within this period of time other reservoirs will be constructed at higher points on the river and such reservoirs would intercept the silt that would, prior to their construction, be deposited in the earlier constructed project. It seems probable that 7,000,000 acre-feet is more than ample for storage capacity for silt.[1]

The building of a large storage reservoir at any point on the river suited to entrap and hold the silt entering the river above the Grand Canyon section will not in itself furnish a complete and immediate solution of the silt problem. Such a reservoir would, however, immediately remove the menace of flood devastation and would enormously reduce the expense in connection with the other aspects of the problem.

1. --- Development of the Lower Colorado River. Wash., D.C., 1928. (U.S.-Dept. of the Interior-Bureau of Reclamation. p.371.)

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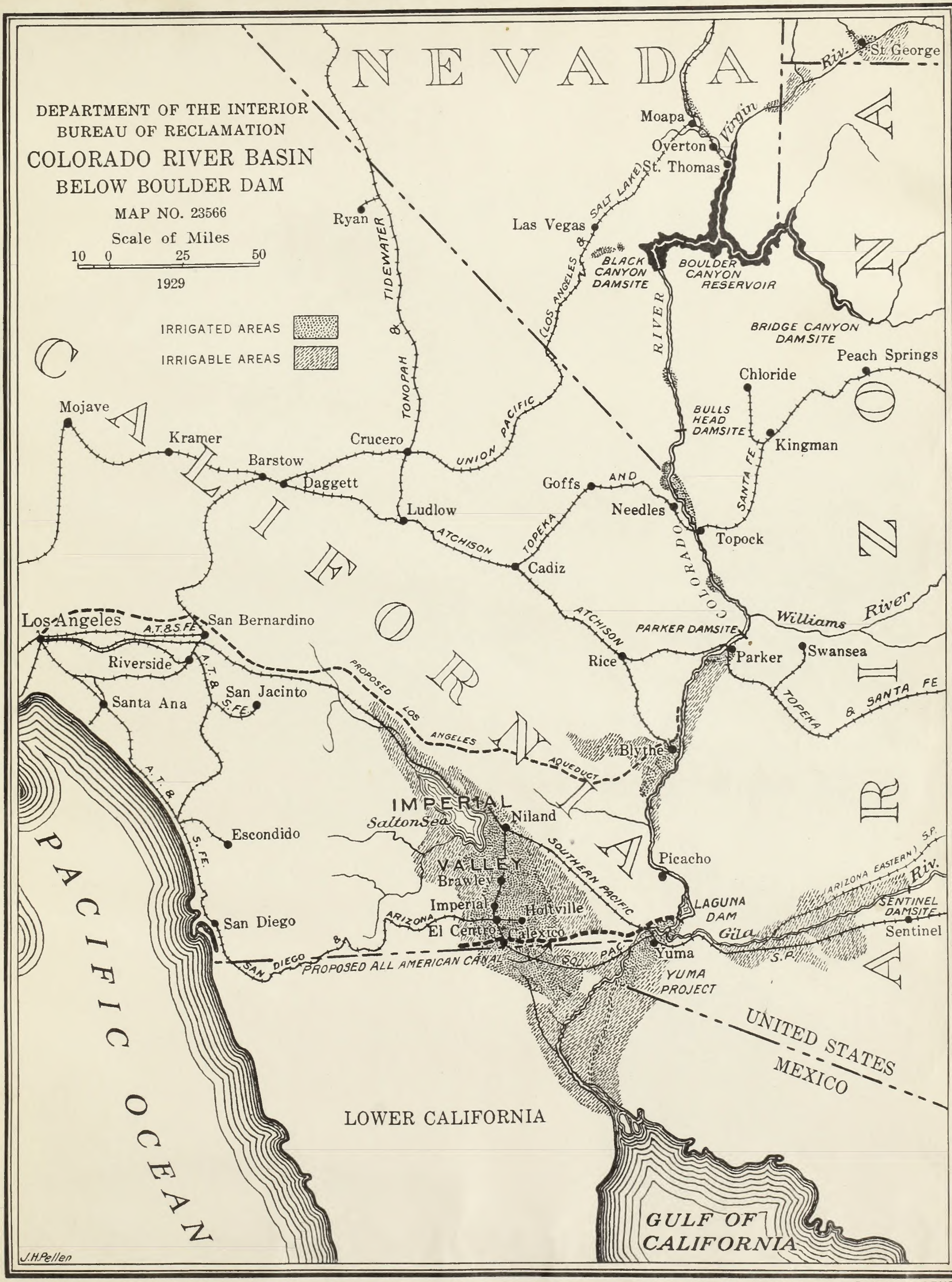

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The silt menace will continue for several years after the completion of such a reservoir, as the desilted water will again pick up previously accumulated bed silt until the flow below the dam scours a comparatively clean channel. Since no practicable large storage sites exist below the Williams and Gila Rivers, the silt from these sources will continue to discharge into the main river; however, the impounding dams to be constructed on the Gila will minimize the flood and silt dangers from this source, while the amount discharged by the Williams is relatively so small as to constitute in itself an item of no serious importance.

a. Determining factors

The building of a reservoir or detention basin is determined by various factors such as the topography of the country, the type, which will also govern its use, and the cost of its construction.

(1) Topography

The topography of the country has an important bearing on the location of the reservoir or detention basin. Reservoirs cannot be built on navigable streams because the interests of shippers would oppose the building of dams across the stream in its navigable parts. Dams could not be built on streams flowing through a plain because the

damage to the land flooded above would offset the benefit to the land protected below. It is only on streams flowing through a hilly or mountainous country that this system could be best applied. The reservoirs at the head of the Mississippi River were constructed by introducing low dams at the outlets of large natural lakes.

The largest artificial storage reservoirs in Europe are found in Russia for the control of the Volga and Meta Rivers. They are similar to those in the Upper Mississippi in America, in that they are natural lakes artificially increased in capacity by the construction of dams. These reservoirs have a total capacity of about 35,000 million cubic feet or 940,000 acre-feet.[1]

There was under construction in 1918, a large water-storage system upon the Ottawa River in Canada. The reservoirs are similar in construction to those at the head of the Mississippi and in Russia for the control of the Volga and Meta Rivers.

(2) Use

Practicability and cost determine whether the surplus water shall be drawn away as rapidly as possible, as in a detention basin, or whether it shall be stored and gradually fed for the use of water supply, water power and navigation. The storage reservoir can be built if the situation makes possible all those uses, and if the values of such

1. Alvord, John W. and Burdick, Charles B. Relief from floods, p. 40.

uses are sufficient to warrant the costs involved.

Where flood protection alone is warranted by the circumstances of the case and the costs involved, the pure detention basin should be used. If a reservoir is useful for flood relief, it must be in such a state of emptiness immediately before the appearance of the flood, that the freshet can be stored, or a sufficient amount of it, to reduce the flow to manageable limits. All works for water storage have a more or less beneficial influence upon floods. It is an attractive possibility to attempt to do more than relieve floods with the reservoirs built for this purpose, by utilizing them for water conservation in the interests of water supply, water power, navigation, sanitation and a general better distribution of the stream flow. The Germans and the Austrians have found it practicable to combine several of these purposes in some of the reservoirs that they have built.

The uses to which a reservoir may be put are often more or less conflicting, thus, a flood reservoir must be empty, ready to catch a flood at any time that the flood may come. It is the endeavor in a municipal water supply to keep the reservoir as nearly full as possible at all times in order to tide over a period of drought. Water stored for irrigation is used during a few months when the crop is developing, whereas a water power project would desirably regulate the water in accordance with the demand for power.

The most benefit is given navigation when storage is drawn upon entirely within the season of minimum gage heights. Special circumstances may make it possible for one or more incidental uses to be properly appurtenant to flood relief.

In the consideration of flood storage there must be known the rates of flood flow and the periods of time through which various rates prevail; in other words, there must be a hydrograph of the flow and time relation. After this information has been obtained, it is a matter of arithmetic to determine the amount of storage that will be required to reduce any given flood to any desired amount. Apex rates are secondary in importance in this problem. The amount of storage is governed by the bulk of flood water above a given amount of flow.

The reservoirs at the head of the Mississippi have been most successful, not only for increasing the low water discharge of the Mississippi River above St. Paul, the purpose for which they were constructed, but also for reducing floods in that portion of the river.[1]

A flood reservoir must always lie empty during the seasons when a great flood may be expected, and in water conservation, a reservoir must be filled prior to a season of drought and kept as nearly full as possible until the drought season is past.

1. Towsend, C. McD. (Scientific American Supplement, Jan. 4, 1913, v. 75: 6.)

These two uses can be accomplished to a greater or less extent in large water-storage projects where practically all the water is caught and stored, but if water must be in storage during the season of great flood, then there must be charged against the reservoir a certain amount of capacity for flood storage, and a certain amount for water storage.

A situation will sometimes be found where the detention basin can be utilized for storing water in the growing season of the year, and safely can be emptied with the approach of winter. Such situations are found upon some of our Middle Western rivers used for water supply, in which the annual flow is much greater than the water-supply requirements and where a certain amount of storage in the late summer and fall would always be effective in insuring the continuity of water supply for municipal purposes.[1]

(3) Types

A storage reservoir may be automatically controlled or not. The reservoir constructed in the thread of the main stream ordinarily is provided with gates of sufficient capacity to waste the water at such rates as may be desired. The dam is usually protected by one or more spillways of such capacity as to prevent the dam from being overtopped if constructed of earth, or to prevent the overflow from reaching a dangerous depth if the dam is built of masonry. The

1. Alvord, John W. and Burdick, Charles B, Relief from floods, p. 150.

use of gates necessitates the human element with its chance to err in the operation of the works, and while gate operation is perfectly satisfactory for water supply, water storage for irrigation and some other purposes, it is desirable for the sake of absolute safety that the human element shall be eliminated to as large a degree as possible in Works for flood relief.

A storage reservoir that is automatically operated has the important advantage that there are no valves to be operated or to fail of operation in an emergency, and no discretion is required as to whether the valves should be opened or closed at any particular time. It has the disadvantage, however, that some of the basin capacity is necessarily occupied long before the flood reaches its apex, and therefore a larger total volume in storage must be provided than would be required if all of the storage could be utilized on the peak of the flood. Therefore, it is necessary that an excess capacity shall be provided above that theoretically required to allow for the inevitable storage early in the flood.

(4) Cost

It has been estimated that to reduce the floods of the Mississippi 1 ft., for a period of 2 months, 13 reservoirs would be required which would cost about $ 70,000,000. The cost of raising the levees 1 ft. has been estimated at about $ 5,000,000.[1]

1. Starling, William. The floods of the Mississippi River, p.53.

The six reservoirs at the head of the Mississippi were begun in 1881 and finished in 1886, at a total cost of $ 1,953,049.53.[1]

The reservoirs which were being constructed on the Ottawa River in Canada were expected to impound 3,850,000 acre-feet at a cost of $ 728,000.[2]

Reservoirs for irrigation purposes have probably reached their fullest development in India, where they have proved a great prevention to famine.

Most parts of India do not have available sites for reservoirs, to be formed by the construction of short dams, and some of the reservoirs are made by dams upwards of two miles in length. It has been estimated that the cost of irrigation does not usually exceed twenty dollars per acre, and sometimes it is less than half of that sum.[3]

The report of the Flood Commission of Pittsburg,Pa., in 1911, recommended the construction of 17 reservoirs to store 59,000,000,000 cubic feet of water at an estimated cost of $ 20,000,000. It was estimated that the future loss at Pittsburgh would be about $ 2,000,000 per annum. Towsend[4] estimates that the cost of storing one day's flow is ample

1. Alvord,John W.and Burdick,Charles B. Relief from floods,p.42.
2. Alvord,John W.and Burdick,Charles B. op.cit.,p.42.
3. Robbins,Arthur G. Discussion of the methods employed for the control of rivers and the prevention of floods,p.16.
4. Towsend,C.McD. (Scientific American Supplement,Jan.4,1913, v.75:6.)

for all the levee construction required on the river, while if reliance is placed on reservoirs, provision must also be made for the other 48 days the river was above a bank-full stage.

Control Measures

Works for flood control do not reduce the flood flows but protect against them. These works include levees, weirs, and channel improvements including channel straightening or enlargement.

1. Levees

A levee is an earthen embankment, of varying cross section and height, for the confinement of a river in its channel. Alvord and Burdick[1] say that the levee is more widely used than any other means for flood relief. The levee system originated on the Nile and the Euphrates long before the Christian Era.

China has used levees to control waters for irrigation. The system of levees has constituted the principal, and often the only method of relief, in every country through which flow rivers liable to produce floods.

The levee system in this country began in 1728, when Bienville constructed the first levee in front of the village of New Orleans, and there has been a steady growth of

1. Alvord, John W. and Burbick, Charles B. Relief from floods, p. 106.

[illegible] the flood construction conducted on the river, which [illegible] be placed in reservoirs, provisions [illegible] done for the [illegible] to keep the water [illegible] [illegible].

Control Measures

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The [illegible] in this country [illegible] the [illegible] levees [illegible] of the [illegible] and there has been a steady growth of

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levee-building for nearly two hundred years. These levees have afforded relief from floods, in the main, but occasionally, during high waters such as those of 1912 and the spring of 1913, they have proved insufficient and caused a great deal of damage by overflow.

Levees along the Mississippi have been built by the joint efforts of the states, through their local levee boards, their state Boards of Engineers, and the Mississippi River Commission. An Act of Congress created the Mississippi River Commission in 1879 which is composed of three engineer officers of the army, usually with the rank of colonel, and not lower than lieutenant-colonel; one engineer of the Coast and Geoditic Survey; two engineers from civil life; and one civilian. General Benjamin Harrison, afterwards President, was the first civilian. He resigned to become United States Senator on March4,1881.[1]

a. Determining factors

(1) Types

The material of which the levees of the Mississippi are to be constructed is, from economical considerations, confined to the limits of an ordinary haul. The Mississippi Valley contains several kinds of earth. They are first, sand; second, clay; and third, loam.

Clay is the best for levees and loam probably the worst of these materials. Clay has the advantage of resisting

1. Ramsdell,Joseph E. (American Review of Reviews,June 1913, v.47:694-5.)

the action of water, whether it is due to waves of the river or to the erosive effect of water percolating through holes or cavities. Water is turned better by clay than either of the other earths. Clay cracks open with dry weather, so that often in summer and autumn, long and wide fissures may be seen, running longitudinally with the levee, but these cracks close, however, when the clay gets wet, and the embankment, if well built, becomes fairly impervious to water.

Sand has the disadvantage of being permeable and loose. The action of waves can affect sand, even when well sodded, and a hole or defect of any kind greatly imperils the existence of the levee. The walls of cavities in this material often fall in and stop the flow, thus giving time to work.

Pure sand when saturated with water is apt to slip or slough on the back or land slope. Where sand is the predominating constituent, the levees are always given a flat back slope, at least three to one, and are reinforced by sodding.

Loam is particularly undesirable because of its lightness and the fineness and want of coherency of its particles. These qualities lessen its usefulness and render it softer and more yielding than sand, and when thoroughly wet it becomes almost a mud. Banks built of this sort of earth are always given extra strength.

Clay does not stand well at grade and is always

settling more or less so that it requires constant looking after and repair to keep it up to standard. The shrinkage of sand and loam is very slight and never beyond a certain point.

Levee-engineers usually consider that a judicious mixture of sand and clay makes, on the whole, the most desirable levee in facility of construction and in qualities of a permanent nature. Sand mixed with clay prevents the latter from cracking and from undue shrinkage, without too much impairing the toughness and resisting qualities of the latter.

Loam stands at grade admirably. It is very permeable, and is likely to slough unless the back slope be flat and well sodded.

The material of which the levee is to be built is usually limited to the location of the proposed embankment. The height will depend on the expected flood height of the water to be confined; the cross section on the strength of the material.

(2) Cost

Since 1865 the local people have contributed about fifty-six million dollars and the national government about twenty-six millions for the construction of levees.[1]

1. Ramsdell, Joseph E. (American Review of Reviews, June 1913, v.47: 694-5.)

2. Channel improvements

The channel of a river may be caused to carry a given flood at a lower gage height by increasing the cross-sectional area of the stream or by increasing the velocity of the flowing water. The area may be increased by dredging or widening the channel. A "cut-off" will increase the velocity of the water.

a. "Cut-offs"

Where rivers are winding "cut-offs" may be used. A cut-off is a channel which is dug to shorten the distance of a river. A straight channel is dug across the bend of a river.

(1) Determining factors

The character of the river bed is an important factor to be considered before a cut-off is made. In a river with a hard and unyielding bed the power of the water tending to adapt the cross section to the new velocities will suffice to excavate the bed only after a long time. When the river flows over a bed of its own deposit, the shape of the cross section will very soon become adapted to the new currents, so that the effect of the cut-off would be beneficial to the country above and not cause trouble below. In a stream with easily eroded banks, the cut-off soon disappears and the stream again becomes winding.

(2) Transient character of

Engineers do not generally approve of cut-offs in rivers of destructive velocity and of movable beds, principally for the reason that their effects are not permanent and they introduce another element of instability where there are already too many. The first effect of a cut-off is to accelerate greatly the velocity in the neighborhood of the new channel, both above and below, and to produce increased erosion of banks and lengthening of bends. This action continues for many years until the river has regained its length. The belief is held that the beds of sedimentary rivers are self-regulating. This view seems to be sustained by experience.

(3) Harmful effects of

In very sluggish and tortuous streams cut-offs may be beneficial in the reclamation of lands, though they are usually more or less detrimental to navigation. As applied to the rapid and unstable Mississippi, they have been shown to be harmful. They produce violent changes of regimen, tearing away valuable plantations and destroying costly lines of levee on the one hand, and condemning considerable towns to decay on the other, by leaving behind them extensive sandbars or unnavigable channels.

The effect of cut-offs on the Mississippi and other rivers is to lower the water at their heads and to raise it at their lower ends.

M. Lombardini states that in the fourteenth century the Po was straightened from Alberta to Monticelli. The levees are only a few feet high at the head of these cut-offs and at the lower end they are sixteen feet high which tends to show that the effect of the cut-offs was to raise the flood level below.[1]

It has been stated that the effect of a cut-off on the Adige, made in 1854, has been to depress the surface of the river above, during the floods since then, and to elevate the surface below; this elevation being equal to about one half of the depression.[2]

Humphreys and Abbot by measurements on the Mississippi have shown that the effect of the Red River and Raccourci cut-offs on the flood of 1851, was to lower the water from four to four and one-half feet above the cut-off and to raise the level below about two feet. The American Bend cut-off, which was constructed in 1858, had a similar effect upon the flood level above and below, during the floods of that year.[3]

The straightening of the Mississippi channel will not go far toward solving the problem of flood relief. The current automatically regulates itself to such speed as the banks will stand. If the distance between two points on the

1. Robbins, Arthur G. Discussion of the methods employed for the control of rivers and the prevention of floods, p. 30.
2. Robbins, Arthur G. op. cit., p. 30-31.
3. Robbins, Arthur G. op. cit., p. 31.

river A to B is fifty miles in a direct line, and one hundred miles as the river flows, the river will erode the banks if straightened to fifty miles until it is again one hundred miles by river from A to B.[1]

The river Theiss in Hungary originally had a very gentle slope, about equal to that of the Illinois River below LaSalle. It was leveed with the result that the height of its floods were increased. The river was then shortened by cutting off the bends, and thus giving it a steeper slope. The first great flood that occurred after the work was completed, rushed through the improved section much faster than the lower part of the river could carry it off. Flood heights were lowered at the upper end, but correspondingly increased at the lower, and in 1897 the town of Szegedin was destroyed by the flood.[2]

A similar method was tried, with similar results, at the Canal de Miribel on the Rhine. Both the high-water and low-water planes were lowered at the upper end of the reach, with great damage to the low-water navigation, while at the lower end they were raised, producing increased flood heights and also injury to the low-water channel.[3]

1. Dickson, Harris. (Saturday Evening Post, Nov. 3, 1928, v. 201: 11.)
2. Towsend, C. McD. (Scientific American Supplement, Jan. 4, 1913, v. 75: 6.)
3. Towsend, C. McD. Op. cit., p. 6.

b. Channel enlargement

A channel may sometimes be improved by enlargement, but such situations are limited.

(1) Limited use of

Few situations exist where extensive betterments in the flood conditions can be secured through the enlargement of the channel by deepening or widening. Local cases are occasionally found where drainage of agricultural lands is financially practicable through this remedy, but usually the property to be protected must be very valuable to warrant the expense of relief by this means. It is usually only valuable municipal property which needs to be protected that warrants extensive improvements of this kind[1]

3. Weirs

Weirs have been successfully used on the Severn and Shannon Rivers, the only inconvenience being the locks required to pass the weir.

Many improvements have been made on this method in France, by building movable weirs, which can be lowered to the bed of the stream in high water, and then offer no resistance to its flow.

They can be quickly and easily raised during low water and thus dam the water back and raise it to navigable depth.

1. Alvord, John W. and Burdick, Charles B. Relief from floods, p.105.

In this country movable weirs are used on the Ohio and some of its tributaries.

Weirs have been built on the River Loire, in France, to prevent the building of levees of extravagant height, and they have proved very efficient and satisfactory. The great argument against them on the Mississippi is that of cost, owing to the length to which they must be carried. The weirs must be so constructed that the water, after passing them, may be most readily carried off to the distant low portions, where part of it remains impounded, as now, in every great flood, and the balance escapes down the natural channels to the outlet of the basin.

Johnson, in 1884, recommended that weirs be constructed on the Mississippi to conduct excess flood waters into the natural outlets from the river to the swamps. He also recommended that the obstructions in the bayous of the swamps between Cairo and the Red River should be removed.[1]

Importance and Application of These Measures

Reforestation is of the greatest importance in mountainous regions and on impermeable soils. A forest can prevent small showers from causing floods, but cannot prevent floods when there is a long and continuous rain. Reforestation is only practicable on such areas that are unsuited

1. Johnson, John Butler. Protection of the Lower Mississippi Valley from overflow, p. 179-181.

for agriculture. The chief importance of a forest cover is that it decreases run-off and hence the amount of water carried to the streams. It has been recommended that reforestation of the Mississippi Valley be carried out as far as possible in order to supplement the other works of flood relief, such as levees, reservoirs, by-passes, and spillways.

Reservoirs are of the most importance at the headwaters of streams. The length of the stream has an important bearing on the effectiveness of reservoirs as a prevention against floods. It has been pointed out that a single storm might sweep through the Mississippi Valley outside the limits of the reservoirs, and cause floods that would inundate hundreds of square miles of territory, were that territory not protected by other methods than that of reservoirs, which in this case would cease to be a protection.

A reservoir must be close to the locality to be benefited or its value rapidly diminishes. While reservoirs materially increase the low water discharge at St.Paul and markedly reduce flood heights, yet 100 miles farther down the river it is impossible to detect their influence during either high or low water.

Reservoirs cannot usually be built in valleys for the area flooded above would offset the value to the area below.

The levee is the most important remedy for flood relief. It is the main reliance of engineers for the control

of the Mississippi. The idea that confining the waters of a river with levees tends to cause a deposit of silt has no evidence to support it.

Cut-offs tend to do more harm than good and are of a transient character. They may be used in some cases but their application is limited.

Channel enlargement is employed in only a few situations. It has been suggested that the levees of the Mississippi be set back from the river at a greater or less distance. The expected decrease in the flood height does not warrant such a measure. The levees would have to be higher because the land slopes from the river.

Weirs have been successfully used in some situations. It has been said that weirs which would reduce the water of the Mississippi River enough to do any good would cause the bayous to overflow their banks. This would necessitate the leveeing of the outlets or bayous. The cost of leveeing a small stream is equal to that of leveeing a large one, so that it would seem better to spend the money on the levees of the main river.

Summary

The primary purpose of flood control is the protection of life and property.

The principal causes of floods are the variation in the intensity of rainfall and of temperature through the successive seasons of the year. A great variety of features of climate, soil, and topography, modifying and blending their effects with infinite complexity, work behind the two prominent causes. Among the most prominent features are the sandy or the impervious structure of the ground, the character of the vegetation, the hilly or level nature of the country, and the proportion of swamp and lake surface to dry land.

Destructive floods have taken place at all times, but lack of data does not enable us to determine whether they are decreasing or increasing.

The preventive measures used for flood relief are reforestation and reservoirs or detention basins.

Works for flood control include levees, weirs, and channel improvements including channel straightening or enlargement.

The importance and application of these measures will depend upon the locality involved. It is possible that one measure will supplement another.

Bibliography

A - Works used extensively

Alvord, John W. and Burdick, Charles B. Relief from floods: the fundamentals of flood prevention, flood protection and the means for determining proper remedies. (New York. McGraw-Hill Book Company. 1918.)

Ashe, W. W. Effect of forests on economic conditions in the Pittsburgh district. (Charities, February 6, 1909, v.21: 827-832.)

Brooks, Benjamin. Do forests hold back the floods? (Technical World, April, 1914, v.21: 198-204.)

--- Causes of collapse. (Current Literature, November, 1911, v.51: 476.)

--- Flood health measures. (Science-New Series, May 27, 1927, v.65: supplement 10.)

Mitchell, Guy Elliott. Is a forest a storage reservoir or a stream regulator? Effect of forest land on navigable streams. (Scientific American, December 28, '12, v.107: 549-50.)

Moore, Willis Luther. A report on the influence of forests on climate and on floods. 38 p. Washington, D.C., 1910.

Oswald, F. L. Floods and their causes. (Lippincott's, 1889, v.44: 237-243.)

--- The prevention of epidemics after the flood. (Science. New Series, August 5, 1927, v.66: supplement 10.)

Reynolds, Robert V.R. Grazing and floods: a study of conditions in the Manti National Forest, Utah. Washington, D.C., September 15,1911. (U.S.-Dept. of Agriculture- Forest service. Bull.91.)

Shepard, Ward. Forests and floods. Washington, D.C., January,1928. (U.S.-Dept.of Agriculture.Circular 19.)

Sherman, E. A. The protection forests of the Mississippi River watershed and their part in flood prevention. Washington,D.C., August,1928. (U.S.-Dept. of Agriculture. Circular 37.)

Stewart, Robert. Soil waste and the flood menace. (New Republic, December 7,1927,v.53:64-67.)

Towsend, C. McD. Controlling the Mississippi River: why the levee system is superior to all other proposed methods. (Scientific American Supplement, January 4,1913,v.75:6-7.)

Zon, Raphael. Forests and water in the light of scientific investigation. Washington,D.C.,1927. (U.S.-Dept. of Agriculture-Forest service.)

B - Works used slightly

Cross, A. N. Swamp drainage and the floods. (Scientific American, May 3, 1913, v. 108: 397.)

--- Development of the Lower Colorado River. Wash., D.C., 1928. (U.S.-Dept. of the Interior-Bureau of Reclamation. p. 369-371, 382-385, 419-421.)

Dickson, Harris. Keeping the father of the waters in the straight and narrow path. (Saturday Evening Post, November 3, 1928, v. 201: 10-11.)

--- Fires that start themselves. (The Literary Digest, January 5, 1929, p. 31-32.)

--- Floods caused by over-grazing. (Scientific American, November 25, 1911, v. 105: 476.)

--- Forests in relation to climate and floods. (Scientific American, October 29, 1910, v. 103: 334.)

Greenleaf, J. L. The times and causes of western floods. (Engineering, March, 1897, v. 12: 949-958.)

Johnson, John Butler. Protection of the Lower Mississippi Valley from overflow. (New York. Reprinted from the Journal of the Association of Engineering Societies for July 1884 p. 169-181.)

Marshall, Logan. The true story of our national calamity of fire, flood and tornado. 1913.

Moore, Willis Luther. Forests and floods. (American Mercury, July 1927, v. 11: 257-263.)

Morgan, Arthur E. Why rivers overflow: how floods may be prevented. (Scientific American Supplement, December 19, 1914, v. 78: 392-394.)

Ransdell, Joseph E. Flood control by levees. (American Review of Reviews, June 1913, v.47:694-696.)

Robbins, Arthur G. Discussion of the methods employed for the control of rivers and the prevention of floods. (1886 Thesis M.I.T. 34 p.)

Smith. Boulder Canyon project. Washington, D.C., March 15, 1928. (U.S.-House of Representatives. Report No.918. p.15-17.)

Soper, George A. The sanitary measures to be adopted after floods. (Scientific American Supplement, June 14, 1902, v.53:22118-22119.)

Starling, William. The floods of the Mississippi River; including an account of their principal causes and effects, and a description of the levee system and other means proposed and tried for the control of the river, with a particular account of the great flood of 1897. (New York. The Engineering News Publishing Company. 1897.)

Willey, Day Allen. Forest destruction and the erosion of arable lands. (Scientific American, May 23, 1908, v.98:372-373.)

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